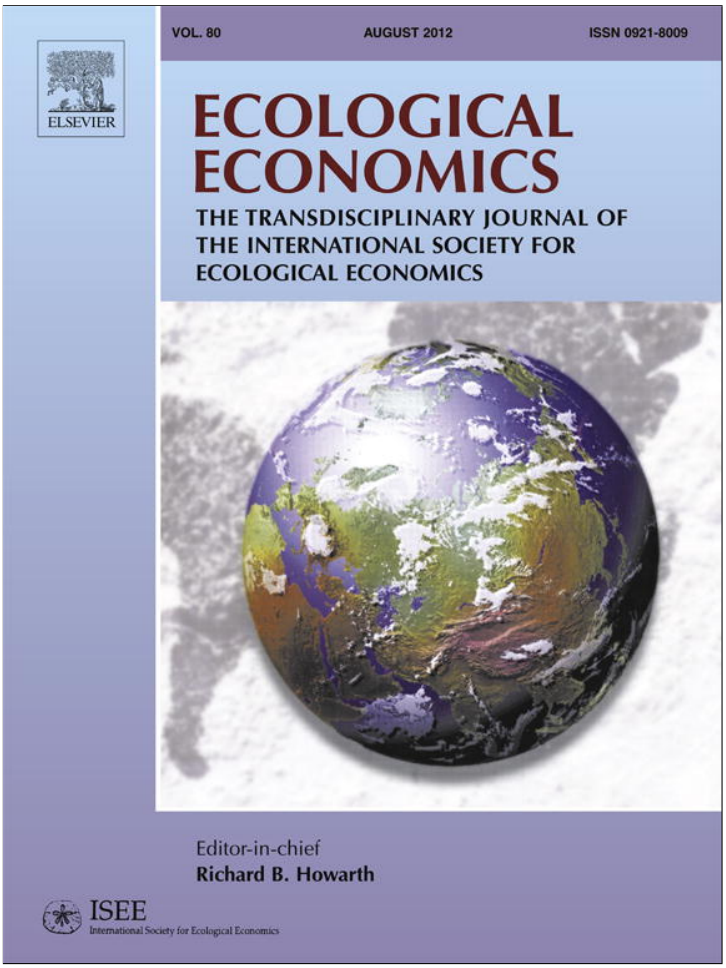

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Analysis

Population matters in ecological economics

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ABSTRACT

It is an axiom of ecological economics that resource depletion and environmental pollution depend on the number of people and how many goods-and-services each consumes, modified by the technological efficiency of production. The paper reviews some studies quantifying the contribution of human numbers to environmental impact. It warns against playing this factor off against that of high consumption in rich countries. It asks whether from the environmental point of view complacency about either present or predicted population size is warranted. The answer depends both on fertility and mortality assumptions and on constraints such as resource and food availability. The concept of cultural carrying capacity would aid societies in determining their optimal population when account is taken not only of subsistence, but of quality of life. A population-control toolkit for both rich and poor societies is sketched, and some controversial, 'coercive' policy possibilities analysed.

Epigraphs: "I was born in a family of 11, so after the death of my father, because we were many, my mother could not help us all. So, everybody has to go and look for his own life. So that's how I came to Kibera." — Joseph Djemba "I've never seen a problem that wouldn't be easier to solve with fewer people." — Sir David Attenborough

1. Introduction

Ecological economics seeks ways to lower environmental impact to sustainable rates of resource consumption and pollution, necessitating analysis of the factors contributing to the impact. For this it has for four decades applied the formula *I = PAT*: amounts of natural-resource consumption and pollution (*Impact*) are a function of number of people (*Population*), how many goods-and-services the average person consumes (*Affluence*), and the amount of natural-resource input or pollution per unit of goods-and-services (*Technology* as efficiency).[1]

I = PAT is more accurately written *I = f(P,A,T)* to indicate that a change in any of the three right-side factor affects the other two (Alcott, 2010). For instance higher population, *ceteris paribus*, means lower affluence (Boserup, 1981, pp ix, 4–5; Cohen, 1995, p 6). Higher affluence lowers mortality and can both raise and lower fertility (Lin, 2010, pp. 260-261).[2] By increasing resource scarcity, higher $P \times A$ increases pressure for greater resource efficiency (lower *T*) (Boserup, 1981; Simon, 1996).[3] Lowering *T* – raising efficiency, *e.g.* in cars or steel production – in turn enables more goods-and-services to be produced (higher *A*, the rebound effect) (Alcott, 2005). Due to this interdependence, autonomous reduction of any right-side factor does not necessarily result in lower impact.[4]

Concerning population reduction, the lesson is that after its first-order effect of freeing up resources, it enables higher affluence. Should a community decrease in numbers whilst the supply of resources remains the same, the smaller number of people can then use the resources for further economic activity; in this case this rebound effect raises present affluence (hopefully reducing poverty) but does not affect impact. Lower *P* is thus not a sufficient condition

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[1] Refinements of *IPAT* include *MEPAT* (Myths and Entitlements) (Swaney, 1991), *STIRPAT* (Stochastic effects) (Dietz and Rosa, 1994, 1997), *I = PACT* (Culture) (Durham, 1992), and *IHAT* (Households) (MacKellar et al., 1995). Each right-side factor can also be endogenous. Note also that *I = PAT* is not an 'identity' but a formula, since each right-side factor is independently measurable (Ehrlich et al., 1973), and that the numerator of *A* is not *I* but goods-and-services.

[2] The demographic transition model shows a stage of relative poverty with high death and high birth rates, followed by decreasing mortality as living standards rise, in turn followed by decreasing fertility as income, education, and female autonomy rise, and finally population stabilisation. Researchers however sometimes observe fertility decline before mortality decline and fertility increase when affluence rises (Abernethy, 1993; Engelman, 2010, p 11; Haub, 2011; Sardon, 2006).

[3] Boserup's position on limits to population size is not as extreme as Simon's (1996/1981) and is reconcilable with Malthus' theory, as shown by Lee (1986), who sides with Malthus against Simon.

[4] Strictly, changes in the *absolute* number *P* cannot be compared with changes in the *ratios A* (whose denominator is *P*) and *T* without further assumptions; *e.g.*, higher *A* means higher *I* only if *P* rises or stays the same or *A* rises faster than *P* falls. Elasticities between the 3 right-side factors are not meaningful.

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for lower *I*. It is not even a necessary condition, because if *A* and *T* decrease sufficiently, *I* could decrease even with rising *P*.

There are two main reasons why population size is nevertheless relevant for ecological economics. (1) Any particular environmental problem – *e.g.* overdrawn groundwater or toxic emissions into groundwater – is easier to solve when there are fewer groundwater consumers. To lower impact the required adjustments in affluence (greater frugality) and technology (greater efficiency) would be physically and psychologically less burdensome; the costs of the benefits of lower impact would be lower. (2) Even if no impact reduction results from population reduction, it raises affluence, and if accompanied by policies for less economic disparity helps alleviate poverty — another goal of ecological economics.

2. Population matters

Because dozens of studies have demonstrated the significant role of (change in) population size in (change in) impact severity, usually by means of regression analysis,[5] this section does not attempt any further proof. It merely looks at several of these studies to show their methods and quantitative results, concluding with challenges to the positions (1) that population doesn't matter and (2) that we must *either* reduce population *or* rich-world consumption.

Using $I = PAT$, Shi (2003) analyses CO_2 emissions in 93 countries between 1976 and 1995. After noting that *A* itself is partly a function of *P* he submits evidence not only for the obvious result that impact rises with population, but for the hypothesis "in the Malthusian tradition" that impact rises disproportionately with population: using the further variables GDP *per capita*, percentage of manufacturing in GDP, and percentage of population in the work force, the population elasticity of CO_2 comes to 1.42 — moreover higher in developing than developed countries.

Brown and Kane (1994, p 56) compare grain production in Western Europe and Africa from 1950 to 1993. Europe saw a 152% (2.5-fold) rise in grain output, Africa one of 118% (2.2-fold). Yet whilst *per capita* output in Europe more than doubled, in Africa it fell, "leaving millions of Africans hungry and physically weakened." Since the ratio of rates of change of total production (2.5:2.2) is much smaller than that of the rates of change in *per capita* production, Africa's higher population increase is a strong explanatory variable.

For deforestation and water use McNeill likewise shows that population size usually outstrips consumption per person (2011, pp 185–187), and decomposition analyses by Bongaarts show that population growth is a key factor in GHG emissions growth (1992, pp 309, 316). MacKellar et al., covering the years 1970–1990 at world scale, attribute roughly one-third of CO_2 emissions to population, a percentage that more than doubles when *P* is households rather than individuals (1995, p 860) — although one could of course subsume smaller households under the affluence rather than the population factor.

Engelman similarly deduces from the simultaneous decrease of *per capita* emissions and increase of total emissions that the number of emitters must be a significant factor (2010, pp 12–13, 27). Raskin, although emphasising large differences in *per capita* resource consumption (affluence), finds that the "impact of population growth in the more developed regions, acting on much higher intensities, was 2.6 times greater than in the less developed regions." (1995, p 230). This in fact suggests that from an environmental point of view population stabilisation in richer countries should take priority over that in poorer countries (*see* Section 5, Fig. 1).

Some voices nevertheless play down the role of population. Princen et al. for example claim that affluence is the main driver of depletion and pollution, boldly stating "It's not population." (2002, p 6). However, not only is there no evidence denying population's contribution, a *reductio ad absurdum* invalidates this view: if 'it's not population', then the next human being has no environmental impact and neither would the 400-billionth. Other economists more explicitly assert the compatibility of limitless growth in population with the planetary resource base (*e.g.* Simon, 1996, pp 11, 579–580, *passim*).[6]

In fact Princen et al.'s empirical findings support neither their extreme conclusion nor their vaguer claim that "increases in resource use can only be explained in part, and often only in small part, by increases in population." (2002, p 6). Their own graphs show worldwide increases between 1965 and 1995 in population compared with (1) forest-products consumption, (2) meat, milk and fish consumption, and (3) water withdrawals. Although regression results are lacking, their own animal-food example shows that *without* the 70% population increase, and holding eating habits (affluence) constant, much less meat and milk would be consumed.[7] For forest products and freshwater as well, population change explains more than a "small part" of total consumption change, and for the claim that affluence growth is "eight to twelve" times as strong a factor as population growth (p 4) no proof is offered.

Satterthwaite similarly negates the population factor after noting the low *per capita* greenhouse gas emissions of the world's two billion poorest (2009, pp 545–548). He rejects *IPAT* in favour of *ICAT* (Consumers) because the poorest purportedly consume nothing at all.[8] To do justice to the kernel of truth in this observation, one could differentiate within $I = PAT$ between various *P*s: each additional person would be given a co-efficient proportionate to their likely (future) affluence, setting at 1 the co-efficient of the poorest new-born child living at subsistence, or "weighting" a country's population growth proportional to its affluence (Lucas, 1976, p 20). Both theory and empirical work indicate, though, that playing off lower consumption among the rich against lower fertility among the poor is illegitimate, if only because population is also increasing in most rich countries, and the affluence of the poor born today is likely to increase (Engelman, 2010, pp 9–10; 26–27).[9]

[5] *See* Commoner (1971); Ehrlich and Ehrlich (1990); Smil (1990); Holdren (1991); Ehrlich (1991); Bongaarts (1992); Hardin (1993); Brown and Kane (1994); Jørgensen (1994); Dietz and Rosa (1994, 1997); Cohen (1995); Engelman (1995, 2010); Harris and Kennedy (1999); Seidl and Tisdell (1999); Turner and Tschirhart (1999); DeHart and Soulé (2000); Brown et al. (2000); Shi (2003); van Vuuren and Bouwman (2005); Atkinson and Gundimeda (2006); Pimentel and Pimentel (2006); Pan et al. (2007); Heinberg (2007); Gonzalez-Martinez et al. (2008); Timah et al. (2008); Feng et al. (2009); Krausmann et al. (2009); McNeill (2011); Brown (2011); Fox (2011).

[6] The journal *Ecological Economics* has published similar work. For Binswanger (1998, p 10) a positive rate of consumption of a non-renewable resource is "sustainable", with the resource "lasting forever". Turner and Tschirhart (1999, p 163) call ever-increasing population not absurd but merely "optimistic". Bazhanov (2007, p 192) asserts that "long-run consumption… can grow infinitely." Krutilla and Reuveny (2006, p 264) seem to regard only "exponential" population growth as inconsistent with a steady-state economy. Cheviakov and Hartwick (2009, pp 2969–2970) allow "never-ending population growth [even assuming] a finite stock of the essential resource input."

[7] Population grew 70% from 3 to 5.1 billion, meat consumption 140%. If, say, 1965 meat consumption was 60 billion kg/year, it would thus rise to 144 billion in 1995. Since per capita consumption rose from 20 to 28 kg/person (+40%), *without* population increase total consumption would be only 84, not 144 billion kg (Princen et al., 2002, p 7).

[8] Apparently unaware of the overwhelming academic consensus, single-solution authors include Monbiot (2009), who relies on Satterthwaite's article to claim that "Population growth is not a problem — it's among those who consume the least." The New Economics Foundation likewise disregards population because it is a "distraction from tackling overconsumption in wealthy countries… — the real problem." (nef, 2009, pp 2, 13) Pearce (2008, 2010a) weighed in with the claim that "green fascism" is expounding "the overpopulation myth."

[9] Many emphasize one *PAT* factor without denying the others: *e.g.* Fox (2011) and to some extent Commoner (1971, pp 133–136, 235) focus on technology; Durning (1992, pp 58–60) and Engelman (1995) weight affluence; Ehrlich and Ehrlich (1990) and Brown and Kane (1994) attribute much to population.

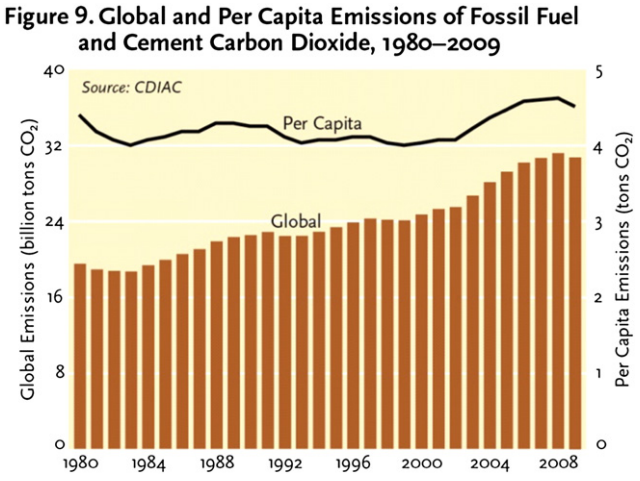


Fig. 1. Per capital consumption increase explains only part of total consumption increase. Source: Worldwatch Institute, Worldwatch Report 183: Population, Climate Change, and Women's Lives; www.worldwatch.org.

3. Complacency *versus* quality of life

Even when accepting that population size burdens the environment to some extent, one can regard population growth with *complacency*: either increased natural-resource efficiency or voluntary sufficiency among richer people will free up environmental and literal space for more people (or higher material living standards among poorer people); or, however *T* and *A* develop, population growth rates are slowing and population size will come to rest within sustainable scale without population policies.[10]

One seminal contribution to the establishment of the *IPAT* paradigm held that solutions should be sought in the realms of affluence and technology rather than population, where we can count on "tendencies for self-regulation." (Commoner, 1971, p 237). Similarly, Schneider et al. regard 8 billion people as sustainable and oppose "state-imposed population control policies." (2010, p 514). Petrucci's (2000) sanguinity is due to his confidence in Marxist environmental solutions without direct attention to population, whilst Hartmann (1998) in like vein chastises "the population lobby" (p 114) for regarding scarcity as biophysical reality rather than an outcome of dominance by large corporations and wealthy governments. Sen's "general case against coercion" in family-planning matters derives from his view that "empirical issues" around food availability and environmental scarcity are not particularly severe, although in the future limits on "reproductive rights" might be necessary on consequentialist, as opposed to purely rights-based, grounds (1996, pp, 1036, 1051, 1039). The most vociferous advocate of the complacency position, though, is Pearce, for whom "the population 'bomb' is being defused." (2010b, pp 4, 170).

The argument is two-pronged: (1) Population will stabilise or decrease without unacceptable loss of welfare and life. (2) The end number is consistent with sustainable resource consumption (and pollution). That is, either our numbers will increase less than usually predicted, and/or the environment can produce more than usually assumed — although nobody claims that Western-style affluence is possible for everybody.

(1) Although most technical aspects of projecting population are beyond the scope of this paper, three parameters warrant mention.

1. UN population studies are not clear concerning mortality trends. A typical one mentions fertility far more often than mortality (UNPF, 2011).[11] It also assumes on the one hand stable crude death rates (between 8 and 13 per thousand), but by 2050 inconsistently predicts an increase in average life expectancy of ten years (*see also* UNDESA, 2009). Other studies note that many now living could see their ninetieth birthdays.[12] Yet declining mortality *per se* weakens the case for complacency.
2. Whilst 2050 world population will be 8 to 11 billion (UNDESA, 2012), uncertainty marking assumptions about changes in education, women's empowerment, and whether crude birth rates in some richer countries will again rise to replacement level seems to speak for caution rather than complacency. Whilst demographic transition theory holds that in addition to contraceptives themselves, 'development is the best contraceptive', empirical data remain ambiguous. When does an additional child become seen as a liability rather than an asset? (Cohen, 1995, pp 46–75, 371–378; *also* footnote 2).
3. UN projections are to a large extent mathematical and demographical only, *i.e.* there is little input of environmental facts on resource availability and tolerable pollution (Brown and Eckholm, 1975, p 191; Cohen, 1995, pp 15, 110–111).

It is with environmental and technological facts, though, that the second argument for complacency mentioned above (non-severe environmental limits) must be addressed.

(2) On this issue of the *human carrying capacity* of either the planet or of individual societies or countries, this paper limits itself to some observations on food production, referring only in passing to the planet-wide meta-analyses of Smil (1994), Cohen (1995) or van den Bergh and Rietveld (2004) and to ongoing work on global environmental footprints (EF) and human appropriation of net primary production (HANPP).[13] Food-production estimates, upon which judgments of maximum *sustainable* population depend, deserve special attention on both environmental and humanitarian grounds.

Based on a survey of literature close to ecological economics,[14] it seems fruitful to group the parameters for judging food production capacity around four questions:

1. What is the net change in the *amount* of arable land and pasture in a given time period — counting loss to building-over, erosion, salinisation, nutrient depletion and other soil degradation?
2. How *productive* is the remaining land — counting both input availability (fertiliser, water, pesticides, herbicides, and high-yield seeds) and limits to input uptake of crops?
3. How sustainable is present, especially 'green-revolution', agriculture compared to bio-organic agriculture that does not *mine* soil, water, fertilisers and fossil fuels?
4. What are the logistics, politics and ethics of food *distribution*?

The agricultural economists surveyed believe yields per hectare can in some places be raised (Brown, 2011, pp 169–170) but in others will fall due to unsustainable systems. They point to sobering facts:

[10] Pro-natalist *values* also play a role; *vide* religious groups and the analyses of Satterthwaite (2009), Pearce (2010b) and Simon, who thought greater numbers would increase the likelihood of geniuses who would solve environmental problems (1996, pp 408, 559–560). Even mainstream demography often regards increasing populations as a good thing (*e.g.* Sardon 2006, pp 198, 219).

[11] The report mentions 'fertility' or 'birth rate' over 120 times, but 'mortality' or 'death rate' 8 times, and omits 'crude death rate' from its tables of demographic indicators (pp 116–121). The relative inattention received by mortality stems perhaps from its non-amenability to policy; in fact, for emotional and ethical reasons societies universally pursue mortality decline, *ceteris paribus* increasing population growth.

[12] https://www.cia.gov/library/reports/general-reports-1/Demo_Trends_For_Web.pdf Ehrlich and Ehrlich (1990), Pearce (2010b, p 286) and Royal Society (2012, pp 30, 42, 101) do treat mortality and fertility on equal footing.

[13] www.footprintnetwork.org and http://www.ecoeco.org/pdf/2007_march_hanpp.pdf or http://www.earthportal.org/?p=777.

[14] Whittaker and Likens (1975); Brown and Kane (1994); Giampietro (1994); Smil (1994); Harris and Kennedy (1999); Brown et al. (2000); Kates (2004); Pimentel and Pimentel (2006); Brown (2011).

- After *intensification* of grain production in some countries, maxima have been reached, *e.g.* for rice in Japan, Indonesia and South Korea, at about five tons (Brown and Kane, 1994, pp 26–27).[15]
- Grain production *per person* rose until 1984 to about 346 tons, fell to 313 tons in 1993 and has continued to fall (Brown, 2011; Brown and Kane, 1994).
- *Irrigation water* presents a limit already overstepped in hundreds of river systems and aquifers.
- Productivity predictions must take into account today's dependence on (decreasing) supplies of *fossil fuels* for fertiliser, machinery, water-pumping and distribution.[16]
- Pesticides, herbicides and monocultures necessary for high-yield agriculture *degrade* the broader environment.
- Arable land and pasture are continually *lost* to erosion, salinisation and building-over for housing and infrastructure (Brown and Kane, 1994, pp 24, 27, 105; Ehrlich, 1991, pp 221–224).
- Fertiliser inputs see *diminishing returns* (Brown and Kane, 1994, p 164).
- Labour and energy costs of *phosphorus supply* are rising (Ashley et al., 2011; Cordell et al., 2009; Smil, 2000).
- Marginal *seed* productivity has declined since the era of Borlaug and the Green Revolution.[17]
- Between 1975 and 2005 the absolute number of *hungry and starving* has increased in 50 least-developed countries (UNCTAD, 2008), as did from 1950 to 1990 the number of "very poor" (Ehrlich and Ehrlich, 1990, p 41; *also* Giampietro, 1994; Pimentel and Pimentel, 2006); worldwide the number has stayed constant for decades.
- The precarious state of fish stocks is common knowledge.
- Bio-engineering and water-desalinisation entail at present little-known risks and costs.

Taken together, the above results caution against complacency, and the agricultural task would obviously be easier were there fewer people to feed. A healthy diet moreover doesn't consist of grain alone.

These facts as well as the widely accepted precautionary principle strengthen the case for higher priority for population policies. In her critique of complacency Kates (2004) adds that demographic transitions happen slowly, that population projections are statistically highly uncertain, and that demographic momentum should not be underestimated.

Aside from environmental or inter-generational considerations, it is often argued that more equitable *intra*-generational food distribution deserves priority; after all, the numbers of the overweight and the hungry are roughly equal. A practical consideration in answer to this is offered by Ehrlich and Ehrlich: There is not time for "waiting for the demographic transition" or for the rich to "change their ways." (1990, pp 214, 40; *also* Daily et al., 1994, pp 470–471; Blake, 1994). That is, can we wait for such re-distribution to occur, a process that would involve widespread changes not only in ethical attitudes but in eating habits?

A conservative conclusion to this section is that, concerning all resources, lower population growth can only help to alleviate poverty — regardless of one's estimate of (1) future population size or (2) carrying capacity. If for instance world-wide no more than 10 tons of GHGs per year is sustainable, the average allowed per person on a contraction-and-convergence basis will be higher with lower population (Engelman, 1995, p 124; Engelman, 2010, pp 10–13, 23). A parallel economic argument is that public finance faces trade-offs between the health and education infrastructure required by additional citizens (Dillard, 2007, pp 29–31) and, for instance, the infrastructure needed for renewable-energy technology. A complacent stance requires moreover the belief that technology can prevent higher impact: population is after all assumed to rise, with no fall in average world affluence (Ekins, 1991).

4. Cultural carrying capacity: $P = I/AT$

This section derives from $I = PAT$ a method by which a country can calculate the population size it desires. To solve for P both sides of $I = PAT$ are divided by AT: $P = I/AT$. The method was formulated rigorously by Penck (1925), an early physical "anthropogeographer" (ecological economist), and used in China before implementing a one-child policy: within the constraints of "economic development,… food resources and the composition of the diet,… and ecological balance and fresh water resources" the guiding studies arrived at a "desirable population size" of 700 million (Song, 1981, pp 27–30).[18]

Penck derived this formula from the facts that total food production is equal to both (1) the number of people times their average food needs and (2) the amount of arable area times its average product. The two right sides being thus equal, we divide both by average nutritional need, and again, P= arable area times product per unit of area divided by average nutritional need (1925, pp 331–332). Product per unit area he calculated using the factors climate, natural soil productivity and technological efficiency; for arable area he had to subtract land needed for clothes, wood, transportation and houses (p 347), but he did not include above-average nutritional requirements or further demands on productive capacity by other species and above-subsistence consumption. The result was carrying capacity as a maximum number.[19]

The term 'cultural' carrying capacity[20] is used to distinguish between carrying capacity at subsistence level – sometimes called the 'giant human feedlot' approach[21] – and the sustainable number at levels of affluence and a style of public life higher than subsistence, always assuming given technologies. That is, not only does desirable carrying capacity depend on environmental givens and the efficiency with which we use natural inputs, but society seeks quality as well as quantity of life (Cohen, 1995, 263–267, 279–287, 317; Whittaker and Likens, 1975). The A variable must be employed in the sense of lifestyle and environmental amenities (Cohen, 1995, pp 165–167, 262; Daly and Cobb, 1989, p 239). Instead of asking how many people the earth *can* support, we can consider *inter*-generational justice as well and ask how many it *should* support (Dillard, 2007, p 7). Fig. 2 shows some categories upon which cultural carrying capacity depends.

To quantify *impact* we rely on biophysical sustainability sciences and seek ever-more accurate estimates of resource supply, climate change, *etc.* In terms of depletion we use the straightforward concept of sustainable harvest of renewable resources, whereas since for non-renewables there is no sustainable harvest, we can only politically decide how long we *want* reserves to last.[22] In terms of local pollution, social optima seem tractable. Required are global cost–benefit analyses in terms of mitigation and adaptation, well-known to ecological economics.

[15] *Also* e.g. http://www.nationmaster.com/graph/agr_cer_yie_kg_per_hec-cereal-yield-kg-per-hectare.

[16] Whittaker and Likes quantified the proportion of food depending on fossil fuels at one-fourth (1975, p 318).

[17] Borlaug himself in 1970 saw that higher hectare productivity merely gave us breathing space because we are not "decreasing the rate of human reproduction." http://nobelprize.org/nobel_prizes/peace/laureates/1970/borlaug-acceptance.html *Also* Brown and Eckholm, 1975, pp 140, 145, 179–196.

[18] 'Development' in the Chinese study means greater resource efficiency, equivalent to this paper's lower T in $I = PAT$; desired were 85 g protein per day.

[19] Penck points out that the point is not Malthus's of the contrast between 'arithmetical' or 'exponential' growth rates: due to physical limits, *no* growth rate is sustainable (1925, p 342).

[20] *See* Boulding (1964, p 135); Hardin (1991, pp 54–56) and Goodland et al. (1991, pp 494–495) [both in Costanza, 1991]; Seidl and Tisdell (1999).

[21] According to Ehrlich (1971, p 91) Colin Clark set the 'human-feedlot' maximum at 157 billion people; the Food and Agricultural Organisation later floated the relatively sober figure of 33 billion [*New Scientist*, 9 August 1984, p 16].

[22] The computations of Hotelling (1931) and Hartwick (1977) notwithstanding, the dilemma is that it is just as 'stupid' to sit freezing on a pile of coal as it is to use it all up.

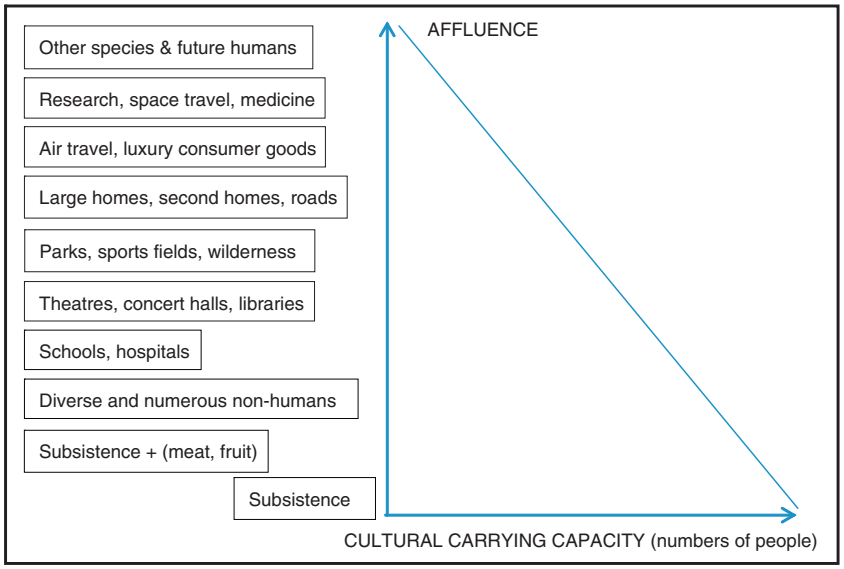


Fig. 2. Within sustainability limits, a society determines its carrying capacity after determining the lifestyle, or affluence, it wishes; natural-resource efficiency could likewise be on the vertical axis, but with efficiency in *descending* scale.

The strength of the *technology* factor *T* is next estimated in terms of the energy costs of harvesting and mining resources and the efficiency with which they are employed in production (food, transport, buildings, *etc.*), always correcting for acceptable risk. The efficiency parameter (metric: GDP/resource input) could be estimated using historical trends. More difficult but more important in the long run, after deciding the *rate* at which we deplete non-renewables, is quantifying *T* assuming no use of fossil fuels.[23]

To illustrate the meaning of this last constraint, it seems that were the work required only for our present mobility to come entirely from biomass, we would have little or nothing left to eat. Brazil, for example, devotes about 10% of its farmland to sugarcane, each hectare yielding about 109 GJ/year of ethanol and meeting about 14% of its vehicles' needs. At the present ratio at which a cane plant is used for sugar and ethanol, meeting *all* Brazil's vehicle demand would require 70% of its farmland.[24] Applying this to the more mobile UK, assume realistically that 'croppable' land is 6,200,000 ha and unrealistically that ethanol productivity equals Brazil's. All UK land could then deliver about 675 PJ/year for vehicles. Yet assuming 30,000,000 autos in the UK, each moving 20,000 km/year, auto-mobility alone requires about three times this much energy.

The third and last factor to quantify is *A*, the socially desired level of affluence. Remember that unless throughput is lower than sustainable scale, any rise in *A* entails a carrying-capacity decline; we face trade-offs between numbers of people and consumption per person.

The political discussion could start with an *A* of mere subsistence — the level of *per capita* throughput consistent with maximum population, yielding *brute carrying capacity*. Estimates of population at this level vary wildly (Cohen, 1995; van den Bergh and Rietveld 2004). A plausible maximum of around 10 billion has been argued (Martinez-Alier, 1987, pp 102–104). However, if we consider only water constraints, and allow for no industrial water use, the figure is more likely between 4 and 7 billion (Cohen, 1995, pp 314–318). In deriving these numbers one must only identify the nutritional level for health; the availability of water, fossil fuels, fertilisers and arable soil has already been calculated under the heading 'impact'.

After assuming perhaps 3000 kcal of food per day and starting with such a maximum, we then begin to calculate the smaller number, *cultural carrying capacity*, by making a series of deductions. First, the society might want more animal protein and fruit in the diet (Smil, 1994, pp 265–266). Under constant assumptions of agricultural input availability and starting from a low plausible maximum under a vegetarian, subsistence-level diet of, say, 6 billion, cultural carrying capacity might then be as low as 2.5 billion (Ehrlich and Ehrlich, 1990, pp 66–67). Another estimation using the same variables yielded the corresponding figures of 5.9 and 2.9 billion (Cohen, 1995, p 209; *also* pp 183–190, 200–205).[25] It should not be forgotten that all such estimates must be based on *sustainable* agriculture; Kates reports an estimate that such a restraint would reduce the sustainable population of the US from about 350 million to about 210 million (2004, p 55).

We then make further deductions based on whether or not we want to keep pets, or use some arable land for sports fields and parks. Further, shall there be room for beauty for its own sake, *e.g.* in museums and as landscape, and for wilderness and habitat for non-human species? These were the factors, after all, that led Mill to argue originally for a stationary-state economy with a stable population (1848, Book IV, Chapter VI; *see also* Gowdy and McDaniel, 1995). However, this trade-off between human population size and such amenities often remains unaddressed by conservationists. The International Union for the Conservation of Nature for example cultivates 15 programme areas, but none addresses human population size (IUCN, 2012).[26] Whatever specific lifestyle a society might choose, it will include not only some comfort and pleasure, but also some *dignity* in its definition of the 'good life'; Heinberg, for one, argues that in addition

[23] On this under-researched question *see* MacKay (2009) , who tallies the land-area and embodied-energy requirements of wind, solar, etc. installations. *Also* Smil (2008).

[24] www.eoearth.org > 'Growing plants for biofuel'.

[25] FAO's website is largely silent on the population issue, focusing more on socio-demographic *structure* than on *size* — a narrowing of the field of 'demography' to exclude size that afflicts much of the literature (Cohen, 1995, pp 12, 235–236); *but see also* http://www.fao.org/docrep/U3550t/u3550t02.htm *and* http://www.fao.org/sd/WPdirect/Wpre0085.htm.

[26] I have not received replies from the IUCN to queries about its views on population size. The World Wildlife Fund employs the concept of Human-Wildlife Conflict (HWC), offering land-use planning and payment for ecosystem services as solutions but taking human population expansion as a given: "If we plan properly, there's room for everyone." http://www.worldwildlife.org/species/humanwildlifeconflict.html WWF's Population, Health, and Environment (PHE) programme mentions only in passing 'voluntary family planning' (http://www.worldwildlife.org/what/communityaction/people/phe/populationhealthenvironment.html) but together with the Population Reference Bureau may be increasing its attention to population stabilisation (De Souza, 2008; Royal Society, 2012, p 102). Conservationist and humanist approaches are contrasted in Bookchin and Foreman (1991).

to dignity, living together democratically in peace depends on a quite low number for cultural carrying capacity (2007, pp 119–122).

P as cultural carrying capacity thus follows from measured or chosen *I*, *T* and *A*. The method outlined here would clarify policy goals and remind us that population size is not just an ecological given but also a social choice.[27] It is moreover best applicable at the country rather than the global level, with countries deciding on trade-offs between higher population and higher affluence (Kates, 2004, p 71). The approach moreover overcomes objections that the concept of carrying capacity is either too static or not subject to empirical investigation (Sayre, 2008). Ecological economics has the tools for doing this work. The question can be re-framed: *Under what assumptions* of *I*, *T* and *A* can we be complacent, or even happy, about *P*?

5. Policies

As seen in the Introduction, population policy is subject to the caveat that isolated reductions of *P*, *A* or *T* do not necessarily reduce *I* because rebound effects induce rises in the other right-side factors; *necessarily* effective ways to reduce *I* would have to be direct, *i.e.* capping or taxing depletion and pollution (Alcott, 2010; Hardaway, 2008). Even lower affluence through voluntary sufficiency among the rich enables higher affluence among the poor, most likely neutralising effects on impact (Alcott, 2008).

There are nevertheless good reasons for separate population policies. As already mentioned, demands on people to increase efficiency and get by with fewer resources *per capita* are less onerous at lower population levels. Locally, moreover, when rebounds are limited by lack of capital and natural-resource imports, reduced environmental pressure can result. However, lower or stabilised population mainly serves *humanitarian* goals.

First, it is commonly estimated that 215 million women wish to have modern birth control technology but don't, meaning 50–70 million unwanted pregnancies per year (perhaps 75% of annual population increase) (Engelman, 2010, p 20; PRB, 2012). Second, at the local level food and water shortages, and thus illness and starvation, could immediately be ameliorated if natality fell (PACCAF, 2010; Royal Society, 2012, p 92). Third, wherever throughput is unsustainably high additional people can only, *ceteris paribus*, raise throughput and thus unethically decrease the welfare of future people (Fletcher, 1976, pp 58–62). Fourth, it is likely that any international agreement capping fuel consumption or GHGs on a *per capita* basis would freeze relative populations in the permit-distribution equation, meaning that population growth among the poorest signatories would lower affluence painfully (Engelman, 2010, p 24).[28] This mirrors earlier agreements between food donors and recipients making aid contingent upon family planning (Fletcher, 1976, pp 57–59).

Consider next population policies for *developed* countries. It is after all a fact that a UK child might consume 22 times as many resources as one in Malawi.[29] As shown in Section 2, it does not follow from this that the elimination of capitalism or over-consumption are sufficient environmental solutions deserving exclusive attention — as argued by Hartmann (1998), Petrucci (2000) or Satterthwaite (2009). It would seem on the contrary to be an argument for population reduction in rich countries.[30]

Since in developed countries women's empowerment, birth-control technology, low infant mortality and legal abortion have largely been achieved, policy could start by removing subsidies for parenting, for example:

- per-child deductions from taxable income per dependent child (often several thousand Euros);
- employment contracts that include monthly supplements per child;
- rewards for births with a one-off payment[31];
- incentives such as pre-school child care, parental birth leave and relatively cheap housing for large families.[32]

By contrast, general tax and benefit structures, including pensions, could favour the childless or at least couples with fewer than three children.[33]

Of course the interests of already-born children deserve priority, even if there are real trade-offs between their welfare and the welfare of those present or future people who would benefit from a smaller population (Blaustein, 1971, p 1860). But if subsidy cuts do lead to unacceptable poverty, these should be addressed with anti-*poverty* policies, not by rejecting environmentally and ethically sound population policies (Engelman, 2010, p 24).[34] Public money saved by removing subsidies could moreover be combined with binding transfers of purchasing power to poorer countries, perhaps tied to education, health, family planning or broader environmental programs.

Many relatively rich people do desire to lower their footprint. In choosing among various behavioural changes thought to reduce individual impact, however, it helps to have a rough idea of relative effectiveness, and the surprising result is that having one less child is many times more effective than several other possible actions taken together — such as cycling, recycling, insulating, avoiding flights, *etc.* (Hall et al., 1994; Murtaugh and Schlax, 2009). This is called the 'offspring effect' (Engelman, 2010, p 11).

The range of *indirect* population-control policies is well-known and includes easy choices such as government propaganda and those associated with the demographic transition such as better education, reproductive health and income security. Sen relies on these – after noting Malthus' underestimation of voluntary fertility reduction and calling on empirical evidence from India and China – to justify his complacent stance that no legal incentives or prohibitions are necessary to limit fertility (1996 pp, 1045–1049, 1053). Cohen lists "six commandments: promote contraceptives; develop economies; save children; empower women; educate men; and do all of the above!" (1995, p 69; *also* 17, 371).

Common to all these measures, as well as to direct ones such as free or cheap medical pregnancy-prevention, is that they are desirable for humanitarian reasons alone, having nothing to do with lowering fertility (Cohen, 1995, p 374; Ehrlich and Ehrlich, 1990; Raina, 1988). They are also relatively cost-effective (Engelman, 1995, pp 116–117; Hardaway, 2008, p 993; Population Matters, 2012) and have been continually discussed.[35] Considerably less discussed in recent years, and absent from Cohen's list, are a range of binding policies:

1. financial incentives and disincentives influencing family size, including taxes on third-plus children, payment for sterilisation, and devolving full financial responsibility for children onto parents
2. rules foreseeing sanctions for non-compliance, including a higher legal age for marriage and child quotas (tradable or non-tradable)[36]

[27] Brown et al., 2000, pp 127–128, 169–170.

[28] Hardin reports that Chinese "production groups" received rice rations with no population inflator (1993, p 269).

[29] Population Matters (2012) http://populationmatters.org/2010/press/climate-change-process-ultimately-fail-populations-stabilised/.

[30] In the words of Ehrlich & Ehrlich, "The world can't afford more Americans." (1990, p 64; *also* pp 42–44, 132–134, 193) nef, in contrast, claims that concern over population means concern over it only among poor countries (2009, p 9).

[31] *See* UNDESA (2009, Table 2) for a list of 36 countries with pro-natalist policies, 22 of them in "more developed regions." On current payouts, land plots and abortion restrictions in Russia *see* IHT (2011). Spain discontinued its 2500-Euro payouts on 1 January 2011.

[32] Daily et al. (1994); Sardon (2006); Thévenon (2011).

[33] *See* Brown and Eckholm, 1975, pp 189–190; Dillard, 2007, p 18.

[34] That is, we should follow Tinbergen's rule of *one problem, one policy* (1956, pp 55–68).

[35] For completeness one must also name the Malthusian 'positive checks' and 'misery' such as war and sickness, as well as infanticide (Harris and Ross, 1987; Hill and Hurtado, 1996; Hrdy, 1999).

[36] Difficult questions around the enforcement of such rules are beyond the scope of this paper.

Because procreation is inter-relational – it quintessentially affects others, and not only offspring themselves – Dillard asks, "Is procreation in all circumstances just… without being subject to law and regard for others?" (2007, p 3). The next section explores more controversial policies in a de-polarising way.

6. Political restrictions on procreative freedom

Today's placement of individual above societal or collective rights has moved several birth control measures to the 'politically incorrect' end of the spectrum — quite obviously for example birth quotas. At least since the 1994 UN International Conference on Population and Development in Cairo an absolute individual right to procreate ('reproduce') dominates population politics (Kates, 2004, pp 56–57; Royal Society, 2012, pp 12–13, 83). It is explicitly upheld for instance by Commoner (1971, pp 234–235, 296), by the dissenting group of most African Academies of Science (Jayaraman, 1993), by Simon (1996) and by the New Economics Foundation (2009, p 10). Sen offers two options – "a big dose of government bullying" and "leaving matters to the responsible [*sic.*] reflection of the people themselves" – and opts for the latter (1996, p, 1044, *passim*).

However, a serious problem attaches to this *laissez-faire* position: Alongside freedoms and rights we also have responsibilities, the more so as the present obese scale of the human economy means the rights of people today conflict with those of people tomorrow. This led Boulding to advocate tradable offspring quotas, arguing that they combine "the minimum of social control necessary to the solution of the problem with a maximum of individual liberty and ethical choice." (1964, p 135).[37] Daly and Cobb likewise do not shy away from this policy, regarding reproduction in the "full-world economy" no longer as a "free good" (1989, pp 236–237, 244–245). For further, more general defences of the rights of society and the future that counterbalance absolute procreative freedom, *see* Engelhardt (1976), Lee (1995), Kates (2004), Heinberg (2007), Dillard (2007) and Brown (2011).[38]

This issue fits neatly into ecological economics' paradigm of the 'commons' (Blaustein, 1971, pp 1904–1911; Kates, 2004, pp 56, 65). If reproduction is an absolute individual right we have "open access reproduction and [a] second tragedy of the commons" (Cohen, 1995, pp 257–258), and it is uncontested that commons problems cannot be solved without limiting access. We limit for instance the number of cows on an alp or GHGs put into the atmosphere, freedom taking a back seat so that one person's rights are not at the expense of another's. But directly limiting the number of people born at all, touching as it does on human intimacy and evolution, is a stark limitation of freedom. Since there are cogent arguments for rejecting anti-natalist measures that intrude upon the physical body, such as forced sterilisation and abortion, or insertion of intrauterine devices (Abrams, 2000), this paper excludes these from consideration.

Nevertheless, the relatively recent severity of global pollution and resource scarcity leads to both rights-based and consequentialist arguments for derogating at least the claimed right to have as many offspring as one wishes (Blaustein, 1971, pp 1891–1893; Lee, 1995, pp 339–340). Justification for limiting this individual freedom closely resembles that for taxation of environmental 'external costs'. Whether seen as a "liberty interest" or a "fundamental right… procreation is inherently interpersonal, and without limitation becomes injurious to others, [involving] limiting duties, and thus countervailing state interests" (Dillard, 2007, pp 11, 20, 24, 49–51). Not least the interests of the yet unborn, under conditions of poverty-inducing environmental constraints, alter the social utility function away from absolute procreative freedom. (*ibid.* pp 11, 19, 41–42; Mainwaring (2004).

Suppose, though, a society does define its cultural carrying capacity as a political goal, but that society adheres to voluntarism in as many realms of life as possible.

> How will the often-asserted right of couples and individuals to control their fertility be reconciled with national demographic goals if the way couples and individuals exercise that right happens not to bring about the demographic goals? (Cohen, 1995, p 378)

Even in terms of their own children, alongside parents' procreative rights stands parental responsibility to support them, a responsibility harder to fulfil as resource supply decreases (Dillard, 2007, p 7; Engelhardt, 1976; Fletcher, 1976; Hardin, 1976).

If procreative rights are absolute (non-derogable), policy options are restricted to education and propaganda or cajoling. One might consider some combination of subsidies and tax rules that influence productive decisions, as mentioned in Section 5, but it would be argued that these, too, abrogate the individual right as much as birth quotas (Abrams, 2000). On the other hand such incentives, as well as cultural norms, today in fact constrain our actions in a *pro*-natalist way, and subsidies could be removed without violating voluntarism (Blake, 1994; Blaustein, 1971, p 1870).[39]

Thus, before deciding between indirect ('soft') and direct ('hard') policies, societies must decide whether individual reproductive rights are absolute or derogable (to be balanced over against the rights of others or society).[40] Arguments for inalienability can be based on principle – either on religious beliefs or a strict *laissez-faire,* individualist philosophy. More contingent arguments could on the other hand be made on the basis of how much society values amenities and the welfare of other species and future humans (*see* Fig. 2).

Also affecting the decision on whether to curtail individual behaviour are empirical estimates of just how severely society is exceeding environmental limits. Even those relatively sanguine on this point, however, concede that significant scarcity is soon quite conceivable (Sen, 1996, pp 1036, 1051). At some point, that is, the rights of future people, whether to resources or procreation, compete with those of present people (Dillard, 2007, pp 57–60; Lee, 1995, p 339). Moreover, as claimed in Section 3, even *intra*-generationally each addition person impedes the fight against poverty — the more so if norms do not change considerably towards more distributive justice. But because they underlie the entire concern with sustainability, it is *inter*-generational ethics that should carry great weight specifically within ecological economics. In terms of present political decisions, moreover, the fact comes into play that neither other species nor future people have any voice, perhaps strengthening the case against unfettered procreative freedom.

The idea of material social justice, however, is still conceptually and emotionally rooted in the present, in the suffering and injustice we can see. When Bookchin, for instance, talks of "social ecology" whilst denying any conflict between "insatiable needs [and] scarce natural resources" (1994, pp 21–24), future humans are not in the equation. Foreman's *inter*-generational and non-anthropocentric answer to Bookchin is that his "biggest worry about the limited perspective of a socially-oriented ecology is that it can all too easily become overwhelmingly social and

[37] Proposals to restrict procreation to licensed parents seek to protect the welfare of children rather than limit population size (Eisenberg, 1994).

[38] On our sacred freedoms Ehrlich and Ehrlich note, "The cost [of deciding for sustainability] would include giving up many things that we now consider to be essential freedoms: The freedom not to consider society's needs when planning a family, freedom to drive gas-guzzling cars,… freedom to use and discard huge amounts of non-biodegradable plastics, and… the freedom to consume more and more" (1990, p 181).

[39] In an earlier, similarly pronatalist context the rebellious 'neo-Malthusian' reaction of sexual intercourse without offspring — by means including illegal contraception and abortion, was of course 'voluntary' and has been called 'bottom-up', although it did advocate the repeal of some laws (Encyclopedia of Ecological Economics, 2012). For a definition of 'neo-Malthusianism' *see* Kates, 2004, p 72).

[40] Cohen for instance questions a land-owner's 'right' to degrade soil, positing society's right to prescribe agricultural practices (1995, p 294).

insufficiently ecological" (Bookchin and Foreman, 1991, p 118). However, since an egalitarian society could still step beyond biophysical limits, the concept of social justice cannot be co-opted by the present.

As with all commons goods we are dealing with an exclusive public good and must decide whether other species and future human beings have rights of access. If and when we find ourselves at an unsustainable level of throughput, we face a trade-off between intra-generational, intra-species individual freedom and inter-generational, inter-species justice. "At issue is how to balance the reproductive rights of the current generation with the survival rights of the next generation" (Brown and Kane, 1994, p 207).[41]

Alongside the issue of whether policies legitimately abrogate or at least derogate individual freedom is the political question of *how* the policies are decided, on a spectrum from authoritarian to direct-democratic. Our debate over regulationist *versus* voluntary approaches is however hindered because key terms such as 'coercion' and 'compulsion' are used ambiguously. In Sen's discussion, for instance, especially when speaking simply of "the Chinese example", the issues of the policies themselves and how the policies are decided are conflated (1996, pp, 1044, 1054). The same ambiguity plagues the terms 'top-down' and 'bottom-up' (*also* Hardin, 1993, p 274). The unhappy result is that one can for instance reject 'coercion' by a dictator, or 'top-down' rule, yet be in favour of measures that 'coercively' restrict freedom if decided by popular majority.[42]

Ehrlich for example writes, "We must have population control at home, hopefully through changes in our value system, but by compulsion if voluntary methods fail" (1971, pp xi–xii). *Population Matters* "opposes coercive population restraint policies."[43] All laws, however, 'coerce' or 'compel' – if left free we would act otherwise – including laws for taxation or compulsory schooling and against bigamy or driving on the wrong side of the road. Since anti-natalist rules are by definition coercive, the anti-coercion position would preclude anything but educational measures and perhaps eased access to contraceptives (Abrams, 2000; but see Lee, 1995; Dillard, 2007, pp 48–49).

But what do the terms 'compulsion' and 'coercive' mean? Dillard's analysis of restrictions on procreative freedom, drawing on U.S. court practice, international law and Locke's theory of government, sees a spectrum of subjective definitions as well as disagreement over when coercion, manipulation, and incentives are unacceptable on human-rights grounds (2007, pp 32–34, *passim*). On the spectrum are the legal policies mentioned at the end of Section 5 (financial incentives and rules such as birth quotas) and intrusions into the body (*e.g.* sterilisation) which we are rejecting. Even the hoary concept of 'mutual coercion, mutually decided upon' misleads because it implies unanimity rather than majority rule. The concept 'coercion', therefore, whilst useful in distinguishing political decision-making regimes, is not useful in discussing population-control policies themselves (Dillard, 2007, p 37; Lee, 1995, pp 335–337).

The equally ambiguous terms 'bottom-up' and 'top-down' likewise have validity only concerning the rule-making *process*. The rules themselves could perhaps always be taxed as 'top-down' – the more so since a government enforces them – but if they are wished and voted in by a majority of the people, the process is 'bottom-up' in contrast to imposition by a non-elected elite. Finally, the hackneyed example of the 'tyranny of the majority' – that not even a 95% majority of voters can legitimately condemn red-heads to jail – reveals that whatever the decision-making regime, society's rights are likewise not unlimited. Again, it is here assumed that surgical intrusions (*e.g.* forced abortions) fall into this category.[44]

It can be safely assumed that most ecological economists would rather 'go to hell democratically' than to heaven autocratically; the 'green authoritarian' option of purely 'top-down' decision-making is not on the table. Consider however for instance large popular majorities for incentives for sterilisation, disincentives for people already having two children,[45] banning trade in sperm and eggs, or closing borders to immigration on environmental grounds? (Löpfe and Vontobel, 2011) The question of which particular (coercive) population policies are out of bounds in a democracy remains wide open.

7. Discussion

In the early years of ecological economics analysis of population size was often explicit, including advocacy of population-reducing policies (Boulding, 1964; Brown and Eckholm, 1975; Daly, 1974; Ehrlich, 1971). The topic has since diminished in importance. Despite a number of articles, albeit analytical as opposed to policy-oriented ones (*see* footnote 5), the journal *Ecological Economics* has published more on technological resource efficiency, renewables and sustainable consumption than on population. Furthermore, to my knowledge no ecological-economics conferences have held sessions on population until the European Society's meeting in Istanbul in 2011.[46] Two *Ecological Economics* textbooks likewise mention population size only briefly and analytically,[47] whilst the seminal anthology of that title (Costanza, 1991) featured among its 32 contributions only one specifically on human numbers (Hardin), two others attesting a positive connection between people and resource consumption (Daly; Goodland et al.), and one adopting a complacent stance towards population growth (Fig. 3) (Cavalcanti).[48]

Neglect of human population size is indeed wider-spread:

> Despite its key contribution to climate change, population plays little role in current discussions on how to address this serious challenge, particularly at the governmental level. Although many policymakers would welcome slower population growth, there is a concern that policies to slow growth will violate the right of couples to determine their own family size. Moreover, population is associated with sensitive issues including sexuality, contraception, abortion, migration, and religion. As a result, the debate on climate change tends to focus on the role of human technologies and their economic foundations, rather than on critical human numbers and behaviours. (Engelman, 2010, p 5).

To be sure, current deliberations of the Intergovernmental Panel on Climate Change on responsibility for historic emissions have revived earlier discussions over the roles of both population and affluence (Agarwal and Narain, 1991; O'Neill et al., 2010). However, the development/environment discussion since the UN Cairo meeting in 1994 has been largely silent on population size (Kates, 2004, pp 57, 68–69; Kysar, 2003, p 727), the topic for instance finding no place

[41] I have framed the possible trade-offs in population ethics in terms of rights; they are treated in terms of interests or utility (well-being) in the 'positional utilitarianism' of Mainwaring (2004, p 354).

[42] Blake observes that "The historical record does not allow us to equate economic and social influence with 'voluntarism' and government policy with 'coercion'." (1994, p 176).

[43] http://populationmatters.org/documents/ethical_implications.pdf *Also* Royal Society (2012, pp 8, 102).

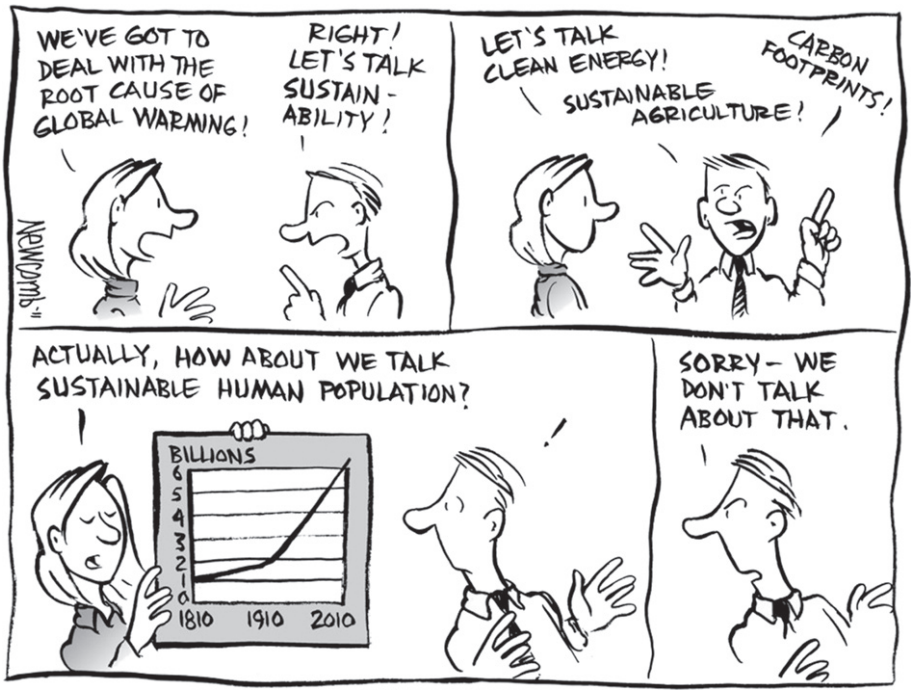
[44] Max Frisch on Swiss radio in 1989 imagined nine people on a cable car from a mountain-top restaurant to the valley station. Seven are drunk and find it great fun to rock and sway the cabin. The two sober passengers are frightened to death. Does the majority have the right to do whatever it wants?

[45] Dillard posits a limited right to self-replacement, congruent with society's interest in perpetuating itself, but not to unlimited numbers of offspring (2007, pp 44–45).

[46] Even for the Istanbul conference the 20 pieces on its website sketching environmental problems in Turkey contained only two peripheral mentions of population — in a republic whose population has quintupled since its founding.

[47] Daly and Farley (2004); Common and Stagl (2005).

[48] For coverage of population issues one must turn *e.g.* to the journals *Population and Environment* and *Population and Development Review* or the organisations Population Council (2002, 2012), Population Reference Bureau (2012), Population Matters (2012), Worldwatch (2012) and – for those with a sense of humour – Voluntary Human Extinction Movement (2012).



With the kind permission of Tim Newcomb.

Fig. 3. With the kind permission of Tim Newcomb.

in the report of the Millennium Summit in 2000 (Hardaway, 2008, pp 987–988; Royal Society, 2012, pp 12–13, 83).

To re-open the population debate one can imagine a conference or special issue on the population views of people and governments of poorer countries. Many developing-country women have long wished fewer children,[49] and there is recent renewed demand that the issue be given priority both locally and in international aid budgets.[50] In the least developed countries "…population growth will increase vulnerability to many of the most serious impacts of climate change", leading 37 of the 49 countries to "explicitly make linkages between climate change and population" for their National Adaptation Programmes for Action (Hardee and Matunga, 2010, pp 115, 118).

One could also revisit controversies over responsibility for environmental stress that arose in New Delhi in 1993, where the scientific academies of 56 developing countries called for zero population growth whilst a majority of the African ones dissented (Jayaraman, 1993; New Delhi Science Summit, 1994).[51] One could learn from China, whose officials routinely cite the demands of a huge population when analysing their fight for instance against desertification.[52] Finally, pro-natalist incentives in rich countries could be rigorously researched.

Emotional and political reasons *not* to look closer at population size are beyond the scope of this paper. Warranting brief mention, though, is the history of links between population control and eugenics (Bookchin, 1994) as well as opposition to food charity and immigration (Lucas, 1976) — despite the fact that contemporary arguments for reduced population maintain neutrality over which groups 'should' reduce. Feminist opposition to low-fertility policies, as well, raised manifold gender issues relating to reproduction (Kates, 2004, pp 58–64). Finally, the issue touches the fact that our humanistic hopes must conform to planetary limits.[53]

8. Conclusions

Six main conclusions of this paper are:

(1) Using the $I=f(P,A,T)$ formula, both population and affluence contribute to the size of impact. Instead of playing these two factors off against each other, research is better directed at measuring their relative contributions with regard to specific impacts.
(2) If it is the case that at desirable levels of affluence *(A)* and realistic increases in resource efficiency (*T*) the present population is not sustainable, it is unwise to complacently ignore population size and/or rely on its natural peaking in several decades. Limits to food production, the precautionary principle and declining death rates all argue against complacency.
(3) Whatever the net effect on impact of lower or stable population, it substantially eases the task of alleviating poverty.
(4) There is a method with which individual countries can approach decisions on optimal population size ('cultural carrying capacity'): After determining sustainable and desirable levels of impact and the desirable level of affluence – including the welfare of future humans and other species – a realistic level of technological efficiency increase in the use of resources can be estimated.

[49] Farley and Leavitt (1971, p 31).
[50] *Also* Daly and Cobb (1989, p 242); UNPF (2011, pp 34–35); PACCAF (2010), a joint statement of NGOs from nine countries in the Horn of Africa, where at the time of writing a new famine is reported. (http://www.independent.co.uk/news/world/africa/starvation-returns-to-the-horn-of-africa-2306001.html).
[51] One document (BBC, 2009) illustrating the need to shift away from Western perspectives asks African focus groups where they place blame for environmental degradation and climate change. The interviewees emphasised deforestation, localised pollution, and overpopulation, generally regarding themselves as responsible and not supporting the researchers' hypothesis that developed-country consumers are to blame. Yet the document's 'Conclusions' avoid population policy, calling principally for teaching the Africans about the guilt of the rich.
[52] *Guardian*, 5 January 2011, p 20; Engelman (2010, p 22).
[53] In the experience of this writer, it is moreover depressing to research the facts of human hunger and crowdedness in the context of dwindling natural resources, disappearing non-human creatures, deaths during childbirth, overfishing, and topsoil degradation — alongside obesity and SUVs.

Using $P = I/AT$ the number of people compatible with these assumptions can then be derived.

(5) When population stabilisation or reduction policies are debated, it should be remembered that they pertain to rich as well as poor societies, and that all policies 'coerce' us, even 'soft' financial (dis-)incentives.

(6) Societies should confront the debate between procreative rights and procreative responsibilities to decide whether reproductive behaviour falls within the realm of activities legitimately controlled by democratic majority.

Ecological economics is well-equipped for many specific tasks:

1. measuring the relative contributions to *I* of *P*, *A* and *T* analytically, using biophysical units;
2. comparing the *cost*-effectiveness of the marginal impact-reduction investment, again in terms of *P*, *A* and *T*;
3. rejecting high estimates of maximum human population, often based on 'huge feedlot' standards, whether on grounds of ecology or present utility;
4. defining sustainable agriculture and measuring its yields per hectare, as well as sustainable fuel use;
5. computing realistic estimates of national cultural carrying capacity so that society can formulate population-size goals;
6. identifying and re-evaluating pro-natalist subsidies;
7. recognising that humans compete with other species for space and resources;
8. answering ethical questions surrounding policies for population constraint within the frameworks of *inter*-generational justice and the dangers of open-access commons; and
9. applying the principle of multi-disciplinarity by explicitly discussing legal and rights issues.

Whilst any given policy to reduce population, affluence, toxicity, or inefficiency can unfortunately be compensated by expansion in other human-ecological realms, negotiating political paths to sustainability requires clear decisions on desirable population goals.

To close with a concrete issue, consider some questions raised by EU efforts for a biological corridor from Orkney to the Black Sea, or American efforts for one from Guatemala through the Darien Gap. Do the EU and the Americas have a moral obligation to use these entire areas agriculturally in order to feed undernourished humans? Are these corridors harder, or easier, to establish if human population grows?

Finite resources imply that population *must* eventually stabilise. Our only choice is to control it consciously, humanely and democratically or to wait for real limits to do it for us. The intent of this paper has been to make room within ecological economics for fresh discussion of our sheer numbers.

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