Optimum population size

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1. Introduction

This chapter focusses on the question of optimal human population size: how many people it is best to have alive on Earth at a given time.

The exercise is one of optimisation subject to constraints. Population axiology is one highly relevant input to the exercise, as it supplies the objective: it tells us which *logically* possible states of affairs – in the sense of assignments of well-being levels to persons – are better than which others.[1] But not all logically possible states of affairs are achievable: we cannot in practice have (say) a population of a quadrillion humans, all living lives of untold bliss, on Earth simultaneously. The real world supplies constraints.

In principle, one could examine the real-world implications, for the question of optimum population, of any population axiology that can coherently be formulated. To keep the task to a manageable size, in this chapter I will focus mainly on the implications of a "totalist" population axiology. According to totalism, the goodness of a state of affairs is given by total well-being (summed across all persons who exist in that state of affairs). Many of the considerations I will survey, however, are also relevant in the context of other axiologies.

One aspect of the literature on optimum population comes from economics, and focusses on abstract formal models. These models are helpful for seeing the relationships between the various relevant considerations, but do not by themselves settle quantitative questions of optimum population size, or even the binary question of which side of the optimum a 'business as usual' population trajectory sits.

The more quantitative questions have practical relevance: once we have worked out on which side of the optimum a 'business as usual' population trajectory sits (and the marginal value of approaching nearer to the optimum), there are things that we can do to try to influence that trajectory. Some such interventions, especially the more coercive, are arguably morally impermissible. But at least some interventions are morally permissible by any reasonable lights. For one thing, there is a continuum between coercion and mild incentives, and clearly some incentive mechanisms are permissible. For another, some interventions take the form of simply *facilitating* higher or lower fertility (through, respectively, fertility treatment and contraceptive services).[2]

[1] Issues of population axiology are discussed in detail in Part I of this volume. For an article-length survey, see (Greaves 2017). The focus in this chapter is on applying, rather than evaluating, particular theories of population axiology.
As is standard in the literature on population axiology, I will discuss only betterness *with respect to welfare*, without denying (or affirming) that non-welfarist considerations may also be relevant to all-things-considered betterness.
[2] This is worth emphasising, since it goes against a consensus that prevailed for a sustained period following the 1994 Cairo Conference on Population and Development. During this period, discussion of deliberate attempts to *influence* (rather than respond to) population size was somewhat taboo Coole (2013, section 5). More recently, however, official governmental and intergovernmental documents have once again begun to countenance taking action to influence population sizes.
Coercive population control is criticised by e.g Dixon-Mueller (1993) and by Echegaray and Saperstein (2010). It is defended by Hardin (1968; 1974). Warwick (1990) and Cohen (1995) offer relatively neutral discussions of

During the long history of discussion of the quantitative questions, there have been concerns both about overpopulation, and about underpopulation.[3] Over at least the past 50 years, however, overpopulation concerns have been far more common, with large population sizes and/or high population growth rates being associated with political instability, environmental degradation, climate change and slower economic growth, as well as simply low levels of per-capita well-being due to overcrowding and thin spreading of resources.[4] This has led to several prominent calls for deliberate action to reduce population size and/or growth rate (e.g. Meadows et al 1972; Union of Concerned Scientists 1992; Royal Society 2012, p.102; UNFPA 2012, pp.10-12; UNFPA 2013, pp.15 and pp.23-5). Accordingly, after discussing the abstract models (section 2), I turn to exposition and critique of these overpopulation concerns (section 3). My verdict will be that the arguments are inconclusive.

There are both static and dynamic elements to the 'population debate'. The static question is that of optimal population *size* at a given time; the dynamic question is that of optimal population *growth rate*. Some of the 'overpopulation' concerns relate specifically to high growth rates, rather than to high sizes. Again mainly for simplicity, in this chapter I focus on static considerations.[5]

2. Economic models of optimum population

Distinguish between *momentary* and *timeless* states of affairs. A momentary state of affairs represents how the world is going at some particular time; a timeless state of affairs represents a whole history of the world.

Correspondingly, the question of optimum population size has an intratemporal and an intertemporal version.[6] Ultimately, our practical interest must be in the intertemporal question. But consideration of the intratemporal case can at least be a useful warm-up and background exercise. Sections 2.1 and 2.2 consider these two questions respectively.

2.1 The intratemporal case

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the variety of possible population-control measures. For the politics and content of the 'Cairo Consensus' in general, see e.g. Halfon (2002).

[3] See Cohen (1995, pp.5-8) for a brief historical sketch. Post-1900, concerns about underpopulation due to falling birth rates, at either the global or national level, are expressed by e.g. (Carr-Saunders 1935; Charles 1936; Harrod 1939; Lorimer, Winston & Kiser 1940, cited by (Gottlieb 1945)). For related reasons, explicitly pro-natalist population policies have been adopted in recent decades in several developed countries (Kramer 2014)). Ord (2012) is agnostic.

[4] Often two or more of these concerns are interlinked: for example, overpopulation might lead to political instability *because* it first leads to diminished well-being and/or environmental degradation. For such relatively broad discussions, see e.g. (Keynes 1919; Ehrlich 1971; Meadows 1972; US National Security Council 1974). Specifically on political instability, see e.g. (Homer-Dixon & Blitt 1998; Robertson 2012, chapter 4). On climate change, see e.g. (Bongaarts 1992; O'Neill 2000; O'Neill et al 2010; O'Neill et al 2012; Spears 2015; Casey and Galor 2017).

[5] The other reasons (besides simplicity) are: (1) the dominant neo-Malthusian concerns are primarily about static rather than dynamic issues; (2) from a long-run point of view the static considerations are arguably more significant (Gottlieb 1945, section IV).

[6] Since the topic is the number of people alive at a given time, rather than the number of people who ever live, we might more strictly label the topic *momentary* population size, rather than population size *simpliciter*. I will use the unqualified term throughout, to avoid cumbersomeness.

The intratemporal question is: which population size at a given time leads to the *intrinsically* best momentary state of affairs at that time, i.e. ignoring the knock-on effects of population size at this time for well-being at subsequent times?

A preliminary remark: It is not obvious that a betterness ranking of *momentary* (rather than timeless) states of affairs even makes sense. There are two reasons one might suspect that it does not make sense. First, on most or all substantive theories of well-being, it is delicate at best whether and how the relevant facts about an individual's life can be indexed to times. For example, conscious experiences arguably supervene on temporally extended processes rather than on instantaneous states, and it is unclear in general how to assign temporal locations to instances of desire-satisfaction (Parfit 1984, p.112; Brink 1997; Bykvist 2015; Bradley 2016; Purves 2017; Bramble 2018). Second, *if* any betterness ranking of instantaneous states of affairs would ultimately have to be derived from a ranking of timeless states of affairs, the exercise may presuppose temporal separability, and temporal separability may be false (Broome 2004, ch. 7).

For the purposes of this chapter, I will simply assume that (one way or another) the exercise does make sense, and in particular that the economists' standard way of carrying out the exercise is by and large defensible, whatever precisely its theoretical foundation is. This assumption seems reasonable, since it is hard to believe that such locutions as "things will be better in 2050 if we take steps now to cut pollution" make no sense at all.

Pressing forward, then: to rank population sizes with respect to (welfarist) betterness in the purely intratemporal sense, the key empirical input is how well-being (at a time) depends on population size (at that time). This in turn depends on many things that themselves vary from one time to another, including, but not limited to: the state of knowledge, social organisation and the natural environment, and the stock of productive capital (such as tools and machines. However, there are some broad qualitative results that hold for any plausible configuration of these background variables.[7] Sections 2.1.1-2.1.3 survey these results.

2.1.1 Abstract analysis

At the most abstract level, we ignore the mediating roles of resources and production, and simply consider average individual well-being (w) as a function of population size (N). In general, one expects this function $w(N)$ to have something like an inverted U-shape. At very low population sizes, well-being per capita is low because the population size is too small to take advantage of economies of scale: at the extreme, the society has its work cut out simply trying to gather produce enough food to feed its members, and cannot support any of the more specialist occupations (manufacturing, printing, advanced medicine, education, etc.) that are required for more than a subsistence standard of living. Similarly, but for different reasons, well-being per capita is also low when the population size is very high: in this case well-being is constrained by overcrowding, pollution and resource shortages, and even in purely economic terms there are 'diseconomies of scale' (beyond a certain point, a factory cannot produce twice as much output even given twice as much labour and capital, since its operations will start to become constrained by e.g. shortages of land and difficulties of waste disposal). Somewhere in between, average well-being reaches a maximum.

[7] At least for the sake of conceptual clarity, it seems worthwhile to recognise these results. One might however be sceptical of the usefulness *in practice* of the concept of optimum population, given the complicated dependence on background variables. Gottlieb (1945) discusses (and rejects) this scepticism.

Which population size is *optimal* of course depends not only on how average well-being varies as a function of population size, but also on which is the correct population axiology. Here, what we need is a 'momentary population axiology', i.e. a betterness ranking of all conceivable momentary states of affairs, rather than the more rankings of timeless states of affairs that the literature on population axiology usually discusses. There is, however, an obvious way to define momentary analogues of the usual menu of population axiologies. For example, momentary averagism and momentary totalism, respectively, say that the value of a momentary state of affairs is given by the average (resp. the sum) of momentary well-being, averaged (resp. summed) across all people who exist at the time in question.[8]

In terms of our function $w(N)$, the optimum population according to momentary averagism, N_{av}^{*}, is obvious: it is simply the point at which $w(N)$ reaches its maximum.

The case of momentary totalism is only slightly more complicated. The optimum population size according to momentary totalism, N_{tot}^{*}, is the one that maximises the area of the rectangle that we get by joining a point on the graph to both the vertical and horizontal axes. Given our assumptions about the shape of the graph, it follows that N_{tot}^{*} is (i) higher than N_{av}^{*}, but (ii) finite. (See Figure 1.)

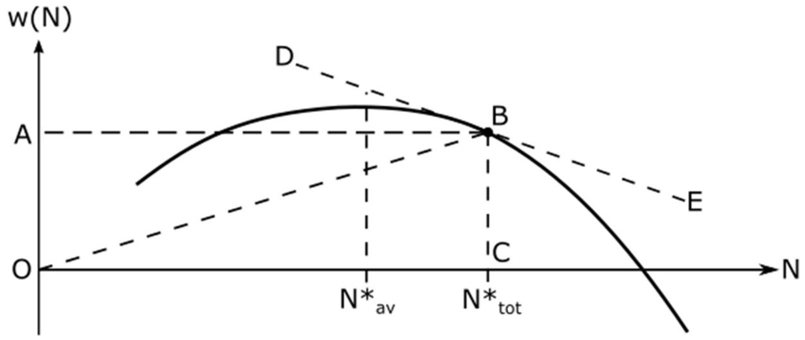

Figure 1: Optimum population sizes according to momentary averagism and momentary totalism, for a typical function $w(N)$. The averagist optimum N_{av}^{*} is the population size at which the function $w(N)$ reaches its maximum. The totalist optimum N_{tot}^{*} is such that the area of the rectangle $OABC$ is greater than that of any other rectangle whose bottom left corner is O and whose top right corner lies on the graph of $w(N)$; it is characterised by the fact that the slope of the tangent line DE is equal in magnitude (and opposite in sign) to that of the line OB (that is, $w(N) = -N.w'(N)$, where $w'(N)$ is the slope of the graph).

It is perhaps worth commenting on the relationship of this result to the Repugnant Conclusion. Setting aside the issue of empirical constraints, and provided the well-being scale has the structure of the real numbers[9], totalism notoriously implies the so-called Repugnant Conclusion: that for any state of affairs and for any positive well-being level $\varepsilon > 0$, there exists a better (sufficiently large-population) state of affairs in which no individual has a well-being level greater than ε ('barely worth living') (see e.g. (Parfit 1984, p.388), (Greaves 2017, p.3), and Part I of this volume). In assessing the extent to which this counterintuitive implication furnishes evidence against totalism, it may be important to note the distinction between this 'theoretical Repugnant Conclusion' and a 'practical Repugnant Conclusion' (Huemer 2008, p.930). The latter would be the conclusion that for any given

[8] The early economic literature on the "theory of optimum population" almost universally assumes momentary averagism (Wicksell 1979, p.146; Wolfe 1926, p.93; Wolfe 1936, p.246; Robbins 2003; Cannan 1918, ch. IV; Cannan 1929, p.81; Gottlieb 1945). Totalism is recognised and explicitly advocated by Sidgwick (1907, pp.415-6); its application in economic models is developed by Meade (1955, ch. VI) and Dasgupta (1969).

[9] More precisely: provided the well-being scale has the Archimedean property. See e.g. (Carlson 2007, p.4; Carlson 2018, secs 3 and 4; Thomas 2018, esp. section 6).

feasible state of affairs and any $\varepsilon > 0$, there is a better feasible state of affairs (i.e., satisfying actual empirical constraints) in which no-one has a well-being level greater than ε. Arguably, the latter is more counterintuitive, and more unacceptable, than the former. We can see from figure 1, though, that totalism does *not* imply the *practical* Repugnant Conclusion, unless quite special and empirically unrealistic assumptions are made about the shape of the graph $w(N)$.

2.1.2 Fixed resources

> "Each additional person… decreases natural resources per head; so that all… resource (and thus many economic and social) problems are easier to solve with fewer people, and harder (and ultimately impossible) with more." *Population Matters (2016)*

The connection between population size and average well-being is of course not brute: it is mediated by what we might broadly term 'resources'. That is, the *reason* why average well-being varies with population size is that the latter affects what quantity of such things as land, bread, fuel, double-glazing and education each person is able to 'consume', and this consumption level in turn affects the person's well-being level.

Instead of simply taking the function $w(N)$ as given, therefore, let us (with slight abuse of notation) consider the function $w(c)$, giving individual well-being as a function of individual 'consumption'.[10] We assume that $w(c)$ (i) is everywhere increasing, (ii) is concave (that is, the graph becomes less steep as c increases), and (iii) crosses the horizontal axis at some positive value c_0 of c (figure 2). Assumption (i) means that more consumption is always better for the individual. Assumption (ii) adds that there are diminishing marginal returns of consumption to well-being: that is, a given amount of additional consumption increases well-being by a smaller amount when the recipient starts from a higher consumption level than when the recipient starts from a lower consumption level. Assumption (iii) adds that for consumption levels below c_0, life is sufficiently miserable that well-being is negative (life is 'worth not living'). All of these assumptions are standard, and generally reasonable.

[10] It is far from obvious that the notion of consumption is flexible enough to accommodate all determinants of well-being. Be this as it may, for tractability (and following standard practice in economics), in this chapter I simply press ahead with developing a simple model based on the assumption that well-being depends on 'consumption' alone.
The function I write $w(c)$ is akin to what economists would call a 'utility function', and would normally write $u(c)$. However, the term 'utility' is often taken to mean specifically a representation of *preferences*, rather than of what is *good* for the individual. Since the two can (arguably) come apart and our interest here is in the latter, I stick to the terminology of 'well-being' rather than 'utility'.

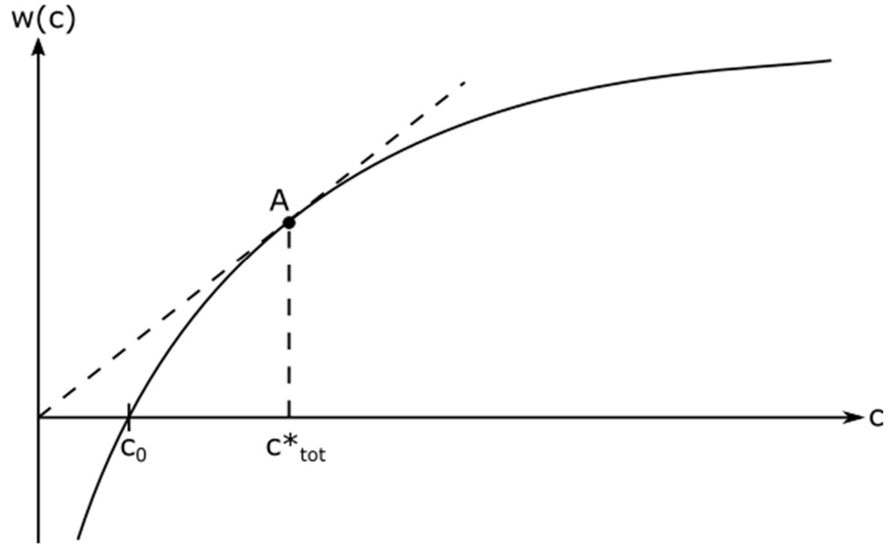

Figure 2: A well-being function $w(c)$ that is (i) everywhere increasing and (ii) everywhere concave, with (iii) a positive horizontal intercept c_0.

Suppose (unrealistically) that the total amount of resources available for consumption is some fixed quantity R, independent of population size – as if such resources were simply given as 'manna from heaven'. It is well recognised that if well-being is the *same* function of consumption for each individual, and satisfies assumptions (i) and (ii) above, then *for any given population size* N, the arrangement that maximises total (and hence average) well-being distributes resources equally among those N people.[11] But what, in this case, would be the optimum population size?[12]

The answer according to momentary averagism is again obvious. Given our assumptions that total consumption is fixed and that well-being is a strictly increasing function of consumption, a smaller population (with equally distributed resources and hence equality of individual well-being) always has a higher individual well-being level than a larger population. The optimal population size is 1.

As for momentary totalism: elementary calculus shows that total well-being is maximised when the per-capita consumption level c is such that $w(c) = c\, w'(c)$. In graphical terms, this corresponds to the point at which a tangent to the graph intersects the origin (point A on figure 2). Having established this optimal consumption level c^*_{tot}, the optimal population size (given the total available resources) is simply whatever population size allows each person to have the consumption level c^*_{tot} (that is, $N^*_{tot} = \frac{R}{c^*_{tot}}$).[13]

It is again instructive to compare the relationship of this model to the 'practical Repugnant Conclusion'. As before, there is no reason to suspect that the optimal situation will correspond to a

[11] This is intuitive: in any unequal arrangement, one could increase total (and average) well-being by transferring a sufficiently small quantity of resources from a richer to a poorer individual, since the amount of well-being lost by the richer individual would (given the above assumptions) be smaller than the amount of well-being gained by the poorer person.

[12] This question of optimal population size given fixed total resources, identical individual well-being functions that depend on consumption only, and no intertemporal considerations is what Blackorby, Bossert and Donaldson (2005, p.287) term the "pure population problem".

[13] Here I assume that population size can be modelled by a continuous parameter. This is a good approximation at large population sizes.

per-capita well-being level that is close to zero. However, the graph does illustrate that the optimal per-capita *consumption* level c^*_{tot} is unlikely to be more than a few times larger than the 'zero well-being' consumption level c_0 (Dasgupta 1969, p.307). (For example, with the utility function as drawn, c^*_{tot} is between two and three times c_0.)[14] *If* intuition says that the optimum must be a situation in which each person can enjoy a consumption level *many times* this 'zero level', this is a counterintuitive result; it is unclear, however, whether the antecedent is true.

2.1.3 Produced resources

> "Every human being represents hands to work, and not just another mouth to feed"
> – George H W Bush (1991)

While total supply is more-or-less independent of population size for some special resources (perhaps land), that is of course not true in general. Almost all resources are in some relevant sense produced by human labour, so that the total amount of the resource increases as population size increases.

To model this, economists use a "production function". In the simplest nontrivial version of this model, this is a function whose single argument is the population size N, and whose value $F(N)$ is the total amount of goods produced. In the previous section (2.1.2), we were in effect assuming that the value of this 'function' was simply a constant, R. More plausibly, though, F is such that average output per head ($\frac{F(N)}{N}$) is low at low populations, rises to a maximum, and decreases again at sufficiently high populations as diseconomies of scale start to set in. For the intratemporal optimum, all of the outputs of production are simply divided equally among the population for consumption, so that per capita consumption is also $\frac{F(N)}{N}$. Given our assumption that well-being is an increasing function of consumption, at a qualitative level this is precisely the situation we discussed in section 2.1.1.

With the additional theoretical apparatus of F in hand, however, we can now say something more precise about the conditions for optimal population size according to totalism. If an additional person is added to the population, three relevant things happen. The first and second both relate to the impact of the additional person on the amount of resources consumed by the pre-existing people. Firstly, the fact that the additional person consumes an amount of goods c means that c must be subtracted from the total consumption of the pre-existing people. Secondly, the additional person increases total production; her marginal product can be *added* to the total consumption of the pre-existing people. The third thing is that there is an additional (and hopefully positive) contribution to total well-being, given by the added person's well-being level. At the optimum, these three contributions to total well-being must balance, so that that the net effect of adding or

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[14] In more detail: for example, to bring c_0 closer to zero while holding c^*_{tot} fixed, given our other assumptions about the shape of the utility function, we would have to put something akin to a 'kink' in the graph of $u(c)$ at or close to c_0.
If we assume (as is common in the economics literature) a well-being function of the 'isoelastic' or 'constant relative risk aversion' form $w(c) = \frac{c^{1-\eta}}{1-\eta} + \alpha$, then we can say something more precise: the relationship between c^*_{tot} and c_0 is then given by $c^*_{tot} = \eta^{\frac{1}{\eta-1}} c_0$. Since the coefficient $\eta^{\frac{1}{\eta-1}}$ takes on values between 1.5 and 2.25 for values of η in the plausible range 1.5-4, this supports the conclusion that c^*_{tot}cannot be many times higher than c_0.

subtracting a marginal person to/from the population is zero.[15] Which numerical value this entails for the optimum population depends, of course, on both the utility function and the production function; it is difficult to say more at any abstract level.[16]

2.2 The intertemporal case

The models in the preceding subsection ask only for the optimal *momentary* state of affairs, and (further) evaluate this without regard to the effects of population at one time for the possibilities available for population sizes and well-being levels at later times. But ultimately, of course, what we seek is the optimal *timeless* state of affairs, from big bang (or anyway from the present day) to heat death.

This means that seeking the optimal momentary state in section 2.1's sense might be myopic. Activities at one time can have both positive and negative effects on the possibilities for well-being at later times. The optimal momentary state of affairs at t *ignoring effects on later times* can therefore easily fail to be part of the optimal *path* (where a 'path' is an assignment of momentary states of affairs to times), just as rational prudential behaviour for a temporally extended individual very rarely coincides with maximisation of prudential value realised in the present moment alone.

In particular: in the intertemporal case, it will in general be optimal for the population at t not to consume everything it produces, but to dedicate some of its output to enhancing future production possibilities. In addition, a society might well decide not to produce as much as it possibly could, if that would lead to environmental degradation that would prove disadvantageous at later times.

2.2.1 Dasgupta's model

The simplest model of these considerations treats all effects of one time on later times as being mediated by a single variable called 'capital'. According to the simple model, (i) capital increases whenever there is an excess of production over consumption (and hence 'saving'), and (ii) the production possibilities at t are determined by the population size at t *together with* the capital stock at t; meanwhile, (iii) well-being depends, as before, on consumption alone.

This model is most intuitive in a highly simplified scenario in which (1) there are no issues of knowledge accumulation or environmental degradation, and (2) only one type of good is produced, which can be either consumed immediately, or reinvested to enhance the production possibilities at future times. For example, the model is a reasonably good fit to a simple farming scenario, in which rice (for instance) can be either consumed this year, or used as seed for next year's crop. 'Capital', in this example, would simply be the quantity of seed grain possessed by the community.

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[15] In symbols, and again assuming a continuous model (cf. fn. 13), the condition is that $w\left(\frac{F(N)}{N}\right) = w'\left(\frac{F(N)}{N}\right)\left(\frac{F(N)}{N} - \frac{d}{dN}F(N)\right)$. Dasgupta (1969) dubs this formula 'The Meade rule', crediting Meade (1955) with the reasoning behind it.

[16] The numbers can of course be crunched for particular specifications of the production and utility functions, but the results are not especially illuminating. For example, if $w(c) = Pc^{0.5} - R$ and $F(N) = QN^{0.5}$ (where P, Q and R are real-valued constants), the optimum population N^* is given by $N^* = \left(\frac{3PQ^{0.5}}{4R}\right)^4$. If the values of P, Q and R happen to be such that $\frac{PQ^{0.5}}{R} = 6300$ (respectively, 420, 70, 11), this gives an optimum population of around 500 trillion (respectively, 10 billion, 8 million, 5 thousand).

The exercise, in this simple model, is to rank the feasible paths (K, C, N) in terms of overall betterness, where:

- K is total capital stock, C is total consumption, and N is population size;
- Each of these variables is itself a function of time;
- Feasibility is constrained by a production function $F(K, N)$, specifying how much can be produced per unit time with a given amount of capital and population size.

Dasgupta (1969) investigates this exercise, assuming a time-discounted totalist axiology. This axiology takes goodness to be given by a double sum: first, for each time we sum total momentary well-being at that time; second, we perform a *weighted* sum across times, in which earlier times are in general weighted more heavily than later times (this differential weighting is the 'time discounting').[17]

Dasgupta then considers two types of production function. The first embodies constant returns to scale: that is, multiplying both of the inputs to production (K and N) by a common amount has the result of multiplying output by that same factor.[18] In this case, Dasgupta shows that the optimum path involves (inter alia) a constant proportional population growth rate, so that (if in addition this rate happens to be positive) population size increases exponentially, without limit (figure 3).

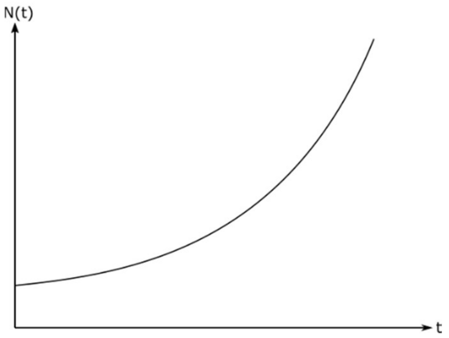

Figure 3: Exponential population growth.

As this last result illustrates, this "constant returns to scale" model is completely unrealistic as a model of the *global* economy, *for all time*, constrained to a finite planet. Production functions that are more realistic for large population sizes involve decreasing returns to scale.[19] For this case, Dasgupta shows that the optimum path tends to a state of constant population size N^* (figure 4);

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[17] In symbols, assuming that at each time there is perfect interpersonal equality of consumption, this amounts to: $V_{tot}^{\rho} = \int dt \cdot e^{-\rho t} \cdot N(t) \cdot w\left(\frac{C(t)}{N(t)}\right)$, where ρ is the discount rate on well-being. In the special case when $\rho = 0$, this reduces to the undiscounted totalist formula $V_{tot} = \int dt \cdot N(t) \cdot w\left(\frac{C(t)}{N(t)}\right)$.
A nonzero discount rate on future well-being is controversial (see e.g. (Greaves 2017, section 7), and references therein). In its defence in the present context, the following two points are worth noting. (1) The assumption is made mainly for mathematical tractability, and one can gain illumination on the undiscounted case by considering the more general discounted case first, and then considering the limit $\rho \to 0$. (2) A small discount rate can be used (within an expected value approach) to account for possibilities of extinction, so that employing a discounted value function need not involve the arguably objectionable assumption that future well-being intrinsically matters less (Dasgupta 1969, p. 308; Stern 2007, pp.46-7).

[18] In symbols: $F(mK, mN) = mF(K, N)$.

[19] That is to say, multiplying both of the inputs to production (K and L) by a common amount has the result of multiplying output by *less* than that factor: $F(mK, mL) < mF(K, L)$.

the numerical value of the size in question is determined by the production function, the utility function and the discount rate.[20]

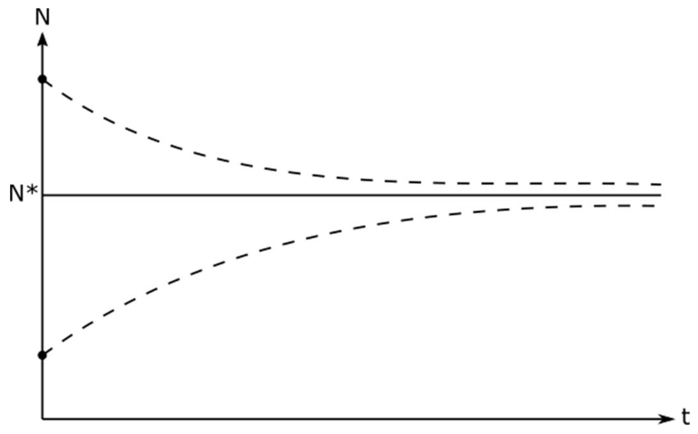

Figure 4: Optimal population paths when the production function exhibits decreasing returns to scale. In this case, there is an optimal long-run population size N^* (corresponding to the solid line); unless the initial population size happens already to coincide with this optimum, the optimal path (dotted line) is one on which population size gradually tends towards the long-run optimum.

2.2.2 Connections between the intertemporal and intratemporal analyses

Since (or insofar as) our practical interest is in the intertemporal question, the different question of which momentary state is optimal *in the purely intratemporal sense*, and thus the analysis in section 2.1, might initially seem irrelevant. However, now that we have seen that (under certain conditions) the optimal population path tends to a constant-population steady state, it seems reasonable to conjecture that this eventual steady state on the optimal path will be identical to the optimal momentary state in an appropriately chosen intratemporal analysis.

If so, then many features of the intratemporal analysis will be relevant to the intertemporal case after all. In particular, it can be shown that in the optimal path's asymptotic steady state, the ratio of the average per-capita consumption rate c to the "zero well-being" consumption rate c_0 is exactly as in the fixed-resources intratemporal model discussed in section 2.1.2 ((Dasgupta 1969, p.307); cf. fn. 14).

2.2.3 Limitations of Dasgupta's model

Two limitations of Dasgupta's modelling exercise are worth noting.

First: the results surveyed in section 2.2.1 do not by themselves say anything about the *numerical value* of (in particular) the optimum long-run population size for planet Earth. As we noted, the model does yield quantitative predictions for the optimal population size *given* specifications of the production function, well-being function and discount rate. But empirical inputs, together with reasonably complicated analysis of those inputs, are required to determine what a plausible production function might be. The contribution of the model itself is to supply conditionals of the form "*if* the production function, utility function and discount rate are thus-and-so, *then* the

[20] In the interests of brevity, my report of Dasgupta's results omits a number of subtleties. For the full details, see (Dasgupta 1969), esp. theorems 2.3 and 3.3 and surrounding discussion.

optimum population trajectory is such-and-such", and (relatedly) to focus debate onto the crucial question of what the real-world production function (etc.) is (cf. fn. 16).

Second: It is also unclear to what extent the simple models that Dasgupta analyses are able *even in principle* to capture the full range of considerations that are involved in real-world debates about optimum population size. As we will see below, some of those are straightforwardly economic concerns about the finitude of fixed natural inputs to production (e.g., land area), and hence are relatively straightforwardly captured by the adoption of a production function that exhibits diminishing marginal returns to scale. But others concern ways in which short-term overproduction and/or overpopulation could damage the planet, and ways in which future progress in technology might enlarge the possibilities. These latter considerations can be captured in the simple model only insofar as the quality of the environment and the state of technology can be counted as part of 'capital', and it is unclear to what extent this is the case.[21]

3. Arguments for downward population control

Suppose we have some model, akin to that of section 2.2.1 or otherwise, that predicts a particular shape for the optimal population path. The crucial question for practical purposes is how the population path that we would expect history to follow under a "business as usual" scenario – that is, a scenario in which no deliberate action is taken to influence the population path in either an upward or a downward direction – relates to this optimal path. As I have noted (section 2.2.3), the model itself does not immediately answer that question.

On this issue, the dominant concern in modern times (i) concerns population *sizes* rather than growth rates, and (ii) holds that under business as usual the population will grow too large, so that *downward* population control, in the form of deliberate attempts to reduce birth rates, is warranted.

Many commonly-heard arguments for this latter conclusion presuppose that the objective is to maximise some notion of average well-being, and are therefore of limited interest to those who reject averagist population axiologies. In sections 3.1 and 3.2, however, I will discuss two notable exceptions. In particular, the evaluative assumptions of the arguments I will discuss are consistent with totalism.[22]

3.1 Ultimate carrying capacity and the threat of increased death rate

> Indefinite population growth being physically impossible, it must stop at some point: either sooner, through fewer births by contraception and humane, pro-active population policy; or later, through more deaths by famine, disease, war, or environmental collapse; or some combination of these. – *Population Matters (2016)*

The first argument appeals to the notion of carrying capacity, a concept from ecology. In simple models of population ecology, one assumes that there is simply a maximum population size (for a given species) that a given environment is physically capable of supporting. This maximum is then

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[21] The literature on growth theory contains various more disaggregated models, including many that explicitly model 'technical progress' (as in the Solow and Ramsey-Cass-Koopmans models – see e.g. (Romer 2012, chs. 1 and 2)), and some that explicitly represent various factors of environment quality separately from produced 'capital' (Freeman et al 2014, chs. 4 and 8). But, as far as I know, no such model has been applied to the question of optimum population.

[22] Note that totalist-compatible arguments for downward population control are of quite general interest, since totalism tends to favour larger population sizes than any other seriously proposed population axiology.

defined as the environment's "carrying capacity" for the species in question.[23] (There is also a more complex notion of carrying capacity that acknowledges the possibility of a population's temporarily "overshooting" its carrying capacity: carrying capacity is then defined to be as the maximum population size that can be sustained *without damaging the environment's ability to support the same species in the future*. The argument discussed here can also be couched in terms of this more complex notion.)

One possibility, then, is that human population size is in danger of crashing into the Earth's carrying capacity in this simple sense. If there is such a hard cap to population size, then any birth rate trajectory that would otherwise have taken the population above this cap must instead result in increases to the death rate. But the latter process would by highly likely to involve large amounts of suffering (via, for example, widespread famine or war). Every plausible population axiology, including totalism, will agree that given a choice between restricting population size via restraint on the birth rate on the one hand, or restricting to the same population size via increases to the death rate along with the associated suffering, the former option is better.

This line of thought is often taken to justify calls for (1) downward population control, (2) in our lifetimes. However, clearly it does not follow, from the mere fact (or claim[24]) that there is *some* limit to population size, that a 'business as usual' population trajectory would reach that limit within any given timeframe. The latter depends on the quantitative details of (i) what the carrying capacity is, and (ii) what the 'business as usual' population trajectory is. We take up these two issues in turn.

Firstly, then: many authors have attempted to estimate the Earth's carrying capacity for humans. A notable feature of this literature, however, is the lack of anything approaching consensus. Cohen (1995, ch.11 and Appendix 3), for instance, surveys 65 such estimates, half of which lie in the range 5-14 billion, but a further third of which are above 20 billion.

This spread of estimates would be less significant if, as is sometimes assumed, the 'business as usual' trajectory were one of never-ending exponential population increase. This assumption was reasonable in the 1960s, since the history of population size up to that did indeed follow a pattern of exponential-like population growth, in particular since the onset of the industrial revolution (figure 5a). And it is easy to see how that assumption led to neo-Malthusian alarm. For example, if population had continued to grow from its 1965 level at 2% per annum, the population size in 2100 and 2200 would have been (respectively) 48 billion and 350 billion. These figures are higher than all but 10 (respectively, all but 4) of the 65 estimates surveyed by Cohen. *If* this were the business as usual scenario, then – given the time delays involved in altering population size via birth rate reduction, and assuming that at least the upper estimates in Cohen's survey are not too conservative – it would indeed seem sensible to start population-reduction measures now.

This, however, leads us to the second issue. As is now well recognised, plausible 'business as usual' population trajectories are not ones of constant-rate exponential growth; the 1960s growth rate of

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[23] See the discussion of "the logistic equation" in e.g. (Vandermeer and Goldberg, 2013, chapter 1, esp. p.16). This equation is a reasonably good fit to population dynamics in artificial environments for some non-human species, e.g. the growth of *in vitro* bacteria cultures (Vandermeer 1969).
Dhondt (1988) is a helpful review of the multiplicity of ways in which "carrying capacity" can be and has been defined. Pulliom and Haddad (1994) focus on the application to human populations in particular.

[24] Most commentators accept this relatively modest claim. A notable apparent exception is Julian Simon (1998, e.g. pp. 580-1). Elsewhere in the same publication, however, Simon sums up his own claim as being (merely) that "there is no *known* ultimate limit to population growth" (ibid, p.78; emphasis added).

2% per annum turned out to be a high point. Worldwide, the population growth rate steadily decreased during the period 1970-2015, reaching 1.2% per annum by 2015 (figure 5c).

Historical data and future estimates regarding fertility rates are perhaps still more revealing. First, a definition: The *net reproduction rate (NRR),* for a given region A at a given time t, is the average number of daughters a woman would bear over the course of her life if at every age, she bore the number of daughters that was average for women of that age across A at t, and was subject to the mortality rate for women of that age in A at t. A constant NRR of one, therefore, corresponds to a situation in which each generation of women exactly replaces itself in terms of numbers, and therefore leads eventually to constant population size, if fertility and mortality rates remain unchanged. Of course, if a country has a preponderance of younger over older people (as is typical in developing countries), population will tend to increase for several decades even if the NRR is one, as new babies are born to reproductive-age couples faster than people die; this is (one aspect of) the phenomenon of “population momentum”.[25]

As for the data: The worldwide NRR fell from 1.7 to 1.1 over the period 1960-2015, and the NRR for “more developed regions” fell over the same period from 1.2 to 0.8 (figure 5d). These data suggest that a correct extrapolation of ‘current trends’ into the future would see world population stabilise and even decline within a few generations. This suggestion indeed seems to be borne out by the UN’s latest population projections, according to which the average *worldwide* growth rate will have fallen to 0.1% by 2100, with the average growth rate excluding the “least developed countries” negative by that date (figure 5c).[26]

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[25] See Weeks (ibid, chapter 6) for more discussion of the concept of the net reproductive rate and related fertility measures. On population momentum, see pp. 339-40.

[26] Data for the periods 1950-2015 and 2015-2100 are from the UN’s historical estimates and “medium variant” projection respectively (UN Population Division 2017). The “more developed regions” are stipulated to be all of Europe and North America, plus Australia, New Zealand and Japan. The “least developed countries” are stipulated to be a particular subset of countries outside those regions (ibid., p. vii). Another helpful overview of the relevant demographic facts is Roser and Ortiz-Ospina (2013).

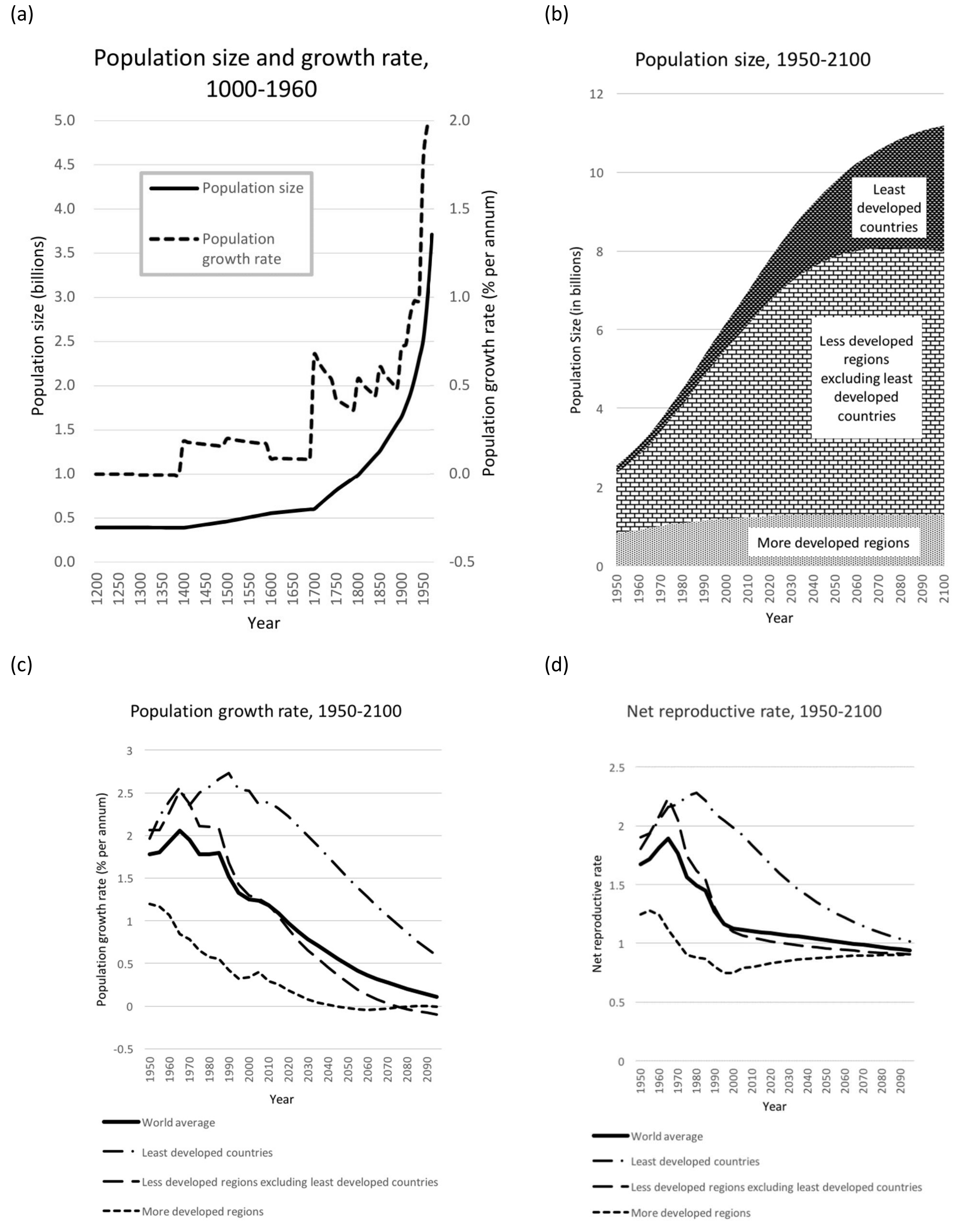

Figure 5: Population estimates and projections. (a) World population size and growth rate 1200-1960. (b) Population size, 1950-2100. (c) Population growth rate, 1950-2100. (d) Net reproductive rate (NRR), 1950-2100. (Source for figure 5a: PBL Netherlands Environmental Assessment Agency, 2010. Source for figures 5b-5d: United Nations, 2017.)

These data and predictions are also readily comprehensible from a theoretical perspective. The theory of the demographic transition holds that as a country modernises, its death rate falls before a corresponding fall in the birth rate. This predicts and explains high population growth rates *for a limited period of time* during the transition, but does not predict that those growth rates will continue indefinitely (see e.g. Weeks 2008, pp.81-91).

For our purposes, the key upshot of all this is that it is not at all clear that there would be any collision between population trajectory and carrying capacity, even without deliberate downward population control, given the actual demographic trends.

To be clear: I am not asserting that there is *no* danger of such a collision. My claim is only that for such collision to be a high-probability prospect any time at all soon, carrying capacity would need to be at the lower end of the range of extant estimates. Therefore, the case for urgent action cannot be made without tangling with the details of those estimates. In particular, we should then note that many of the more conservative estimates tend to be relatively pessimistic about technical progress, assuming that key variables (such as food production per unit land area, or population density) cannot conceivably rise more than a few times their actual values at the author's time of writing, while 'technological optimists' dispute this.[27]

3.2 Short-term overpopulation, environmental degradation and long-term carrying capacity

> "Environmental degradation, including climate change and resource depletion, is steadily reducing the number of people the Earth can indefinitely sustain." – *Population Matters (2016)*
>
> "[H]igh fertility leads to resource problems which then lead to solutions to the problems which usually leave humanity better off than if the problems had not arisen." – *Julian Simon (1998, pp.75-6)*

The second totalist-compatible argument for population reduction I will survey appeals to the idea that too high a population in the short to medium term might be myopic. More precisely: recall that the totalist seeks to maximise total welfare *across all time*, and not merely total welfare *now* or *during the next generation*. As a result, anything that significantly reduces either future carrying capacity, or future average well-being (or both), is likely to be of negative value on balance by totalist lights, even if it increases the total amount of welfare realised during (say) the next 30 years.

The claim then is that under a business usual path, population sizes will soon be (or perhaps already are) above the level that would optimise the combination of future carrying capacity and/or future average well-being, for reasons of environmental degradation.

The key objection to this claim (and, more generally, to any claim that environmental degradation due to high population is an indicator that the population size is "in overshoot" *and therefore above optimal*) involves the 'Boserupian account of innovation'.

To understand this account, note first that (as all discussants agree) carrying capacity *for humans* is not a time-invariant matter: it is relative to level of technological sophistication, and therefore tends

[27]For concreteness, here is one example. Meadows et al (1972, figure 10) assume a maximum conceivable food productivity per unit land area of four times the average at their time of writing, leading to a minimum requirement of 0.1 hectares of arable land per person fed. Simon (1998, pp.100-101), writing 26 years later, reports an (actual) example of hi-tech commercially viable farming producing enough food for 500-1000 people per 0.4 hectares, i.e. 125-250 times the cap assumed by Meadows et al.

to rise over time. Throughout recent(ish) history, for instance, carrying capacity has increased dramatically, as e.g. food production systems have become vastly more sophisticated.

The key question then is the direction of causation between population increase and technological progress, at each stage of this process.

According to those who advocate limiting population at any given time to carrying capacity at that time – i.e. avoiding 'overshoot' – the relevant technological developments have exogenous causes, and merely permit an otherwise-temporary population increase to become permanent. If that were true, the optimal strategy would presumably be to wait for the developments in question to occur, and *only then* to increase population towards the new, higher carrying capacity.

According to 'Boserupians', in contrast, necessity is the mother of invention: it is precisely the problems involved in temporary overshoot that *cause* a community to develop and/or adopt more sophisticated technologies, thus raising the carrying capacity to something above the existing population size. Boserup (1976) argues convincingly for this latter direction of causation in the case of the history of agriculture in Europe, from hunter-gatherer systems capable of sustaining only very low population densities, through to advanced agricultural systems supporting cities.[28]

Note that a Boserupian account of innovation would not support *ignoring* concerns about sustainability, and simply allowing population to increase *without giving any thought to* the resulting overshoots. That course would indeed lead to population crashes post-overshoot, and also would involve lesser technological progress. What the Boserupian account does suggest (though) is that it would in general be a mistake to infer, from environmental degradation, that deliberate population control is the best response, so as to keep population within the existing carrying capacity. Had the agriculturalists of Europe taken that latter course, we might still have the agricultural systems, lifestyles and population densities of 4500BC; we would surgically have removed the spur to progress, rather than progressing. According to the Boserupian account, then, in general one *expects* to encounter temporary overshoot and related problems of environmental degradation, as part of the natural course of things *on even the optimal trajectory*.

Inter alia, the Boserupian theory, insofar as it is correct, threatens to undermine the argument for population reduction with which I began this section, as follows. It may be true that for reasons of environmental degradation, higher short-term populations would, *other things being equal*, reduce long-term total well-being. But, according to the Boserupian theory, other relevant things would not be equal: the higher short-term population would accelerate technological progress in ways that tend to increase carrying capacity, and this latter effect may more than offset any decrease in carrying capacity due to environmental degradation.

I say only '*threatens* to undermine', and '*may* more than offset'. Which of the two factors (environmental degradation or overshoot-fuelled technological progress) is more significant in a given case depends both on how serious the environmental degradation is, and on how great the prospects for technological improvement are. On the latter question in particular, as I noted above, there is a wide range of views, with 'optimists' inclined to think that plausible technological development will easily increase carrying capacity enough to keep pace with business-as-usual population growth, and 'pessimists' taking the opposite view. Since this disagreement in general concerns credences regarding progress from technological developments *whose details are not yet*

[28] It is easy to see how the Boserupian mechanism can be mediated by economic incentives: as a resource becomes more scarce, its price rises. This generates powerful incentives, both for producers and consumers, to shift towards usage patterns that are more efficient with respect to use of the scarce resource.

envisaged, it seems to be largely a matter of differences in intellectual temperament, and somewhat intractable to resolve by appeal to hard evidence and/or rational argument.[29]

4. Summary

This chapter has examined the question of optimum population size, and (relatedly) whether a 'business as usual' trajectory would take us above or below the optimal population-size path. These questions are decision-relevant not only for population policies whose explicit aim is to influence the population size, but also for the many other policies that foreseeably affect population size.

Which population size is optimal (under given empirical conditions) clearly depends on which population axiology is correct. In this chapter, for the most part I have restricted attention to the implications of a totalist axiology.

Section 2 surveyed abstract economic models, first of optimum population size in a purely intratemporal sense (section 2.1), and then of the optimum population path through time (section 2.2), given a simple model of how population size at one time affects the background conditions at later times. While highly abstract, these models allow us to represent, *inter alia*, the ideas that most resources for consumption are in some relevant sense produced by people, that production typically exhibits diminishing returns to scale at sufficiently large population sizes, and that saving at earlier times facilitates supporting a larger population at later times. The most sophisticated such model I surveyed, that of Dasgupta (1969), suggests an optimal population path that gradually tends to some finite asymptote, presumably interpretable as the optimal population size from an intratemporal perspective, given optimal capital stocks, and once all possible technological progress has taken place. While Dasgupta's model does not involve any explicit representation of the state of the environment or technological progress – two matters that are key to the more applied discussion of optimum population in the 20th and 21st centuries – it is perhaps a close enough approximation to be helpful in organising thoughts. What no such abstract model can do, by itself, is supply quantitative answers to questions about optimal population size, since the models quite appropriately contain several free parameters.

In section 3, I surveyed two of the more important arguments for the claim that deliberate attempts to reduce the birth rate are warranted because the population trajectory under a 'business as usual' scenario is (now and/or in the near future) above the optimal population path. One distinctive feature of these arguments – and one reason I have singled them out as being among the more important – is that, in terms of population-axiological assumptions, these arguments are compatible even with totalism. The first argument centres around the idea that a 'business as usual' trajectory is on a collision course with carrying capacity, so that we face a simple choice between reducing the birth rate or experiencing an increase in the death rate. The second centres around the idea that overpopulation in the short term is reducing the Earth's long-term carrying capacity.

I did not find either argument to be conclusive. In reply to the first argument, I noted that (i) a plausible 'business as usual' population path is not one of constant-rate exponential growth, but

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[29]This dispute at times degenerates into interdisciplinary mud-slinging. For example, responding to the suggestion that technological progress will render present trends of increase in both standards of living and population consistent with carrying capacity, for instance, 'pessimists' Daily and Ehrlich remark that "this assertion represents a level of optimism held primarily by non-scientists" (ibid., p.763); it is clear from the context that the intended implication is derogatory. 'Optimist' Julian Simon responds that scientists who are experts in the closest-to-relevant field often tend to be peculiarly ill-placed to estimate future progress, as their expertise in present technological limits psychologically blinds them to the possibility of the as-yet-unthinkable (ibid., 1998).

rather has population growth rates dropping to near-zero, or even below zero, within a few generations; (ii) it is not at all clear that the relevant carrying capacity, taking into account plausible technological progress, will be low enough at any point in time to collide with these more plausible population paths. In response to the second, I noted that the Boserupian account of innovation explains why some degree of 'population overshoot' and environmental degradation would be expected even on the optimal population path, and why it might be that even if overshoot-induced environmental degradation reduces future carrying capacity *other things being equal*, it might increase future carrying capacity *in fact*.

In both cases, my conclusion is only that it is *unclear* whether or not a business as usual trajectory would take population sizes above the optimalu path (in significant part, because it is unclear what degree of technological optimism vs pessimism is appropriate). I therefore close with the cliché that resolution of this question (if possible at all) would require further careful, unbiased research. The cliché is however perhaps more interesting than usual, since most participants in 'the population debate' either take it to be obvious that business as usual would involve above-optimum population sizes, or regard public discussion of optimum population size as morally inappropriate.

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