
PERSPECTIVE ARTICLE

The economics of transition to a Steady State Economy

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Abstract

This article examines the economic transition from a growth-oriented capitalist economy to a Steady State Economy (SSE), with particular emphasis on the role of population reduction in achieving ecological equilibrium. Drawing on Daly's foundational framework, the paper analyses the demographic, labour market and distributional consequences of a gradual decline in population, arguing that such a decline need not produce recession or lasting social harm. Using the IPAT equation and current ecological footprint data – which show humanity's demands running at 178 per cent of the planet's bio-capacity – the paper estimates that sustainable world population lies in the range of 1.3 to 3.5 billion people, far below the current 8.2 billion. The paper concludes that, while voluntary population reduction is unlikely to succeed without binding international agreement, a coordinated global policy of reduced fertility remains the most viable path to long-term ecological and economic sustainability.

Keywords: Steady State Economy; ecological equilibrium; population reduction; ecological footprint; sustainable development

1. Introduction

The purpose of this essay is to examine the path that a capitalist economy would follow in its transition to a steady state with substantially lower population. A basic

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requirement for the Steady State Economy (SSE) is that the size of population is kept constant and in accordance with the available resources and technology of production. Population is an important variable in the economy and its changing size has always been a source of concern among economists and other scientists. As far back as the fourth century BC, Plato (*Laws*) and Aristotle (*Politics*) were concerned about overpopulation and suggested a constant land-population ratio (Plato, 1926; Aristotle, 1932). In the early sixteenth century AD., Thomas More wrote his *Utopia*, where every city has a constant number of 6,000 families (More, 1551). At the end of the eighteenth century, Malthus published anonymously his *Essay on the Principle of Population* and five years later, in 1803, an enlarged version appeared with his name on it, where he suggests ways for population reduction in order to avoid poverty (Malthus, 1803).

More recently, Alvin Hansen, in his presidential address to the American Economic Association in 1938, expressed fears that the decline of population growth would lead to a reduction of investment. If population declines, an important outlet for investment will be closed. Thus, the idea of secular stagnation was introduced (Hansen, 1939). A few years earlier Keynes (1931) was arguing for population stability, claiming that with no major wars and no important increases in population, the economic problem might be solved within a hundred years, at the same time expressing a fear that unemployment might be a problem. The first reaction to Hansen's fears came from Schumpeter (1943: ch. X) who argued that population ageing and population decline do not need to restrict output neither from the demand side or from the supply side.

In the years following the end of the Second World War, when the world population was rapidly growing, the interesting question was not how the low rates of population growth might affect total output but exactly the opposite, i.e., how very high growth rates might affect output. During the 1920–1930 and the 1930–1940 decades, the world population grew by 9.2% and 10.6%, respectively, whereas in the next two decades the growth rates were 9.1% and 20.8% (Gapminder.org, 2022). Simon Kuznets, in a 1967 paper, examined the question 'to what extent does a high rate of population growth impede the growth of product per capita' (Kuznets, 1967). A year later the publication of Paul Ehrlich's *The Population Bomb* made the population explosion a world issue (Ehrlich, 1968).

Given the present concerns about rising global temperature, climate change, ecological footprint being 178 per cent of bio-capacity² and overpopulation, it is interesting to examine the transition of an economy to a steady state level with lower population and ecological balance. The factors involved in achieving ecological equilibrium and keeping human activities within the planetary limits are three, namely the size of population, per capita consumption (often called affluence) and technological methods used in the production and consumption of material goods and services.

Optimists about the prospects for reform differ markedly in how they propose to achieve it. Some (green growth advocates and eco-modernists) rely on technological innovations ranging from renewable energy sources and nuclear energy to spreading crushed rocks over farmland to capture carbon dioxide. Some (degrowth theorists) suggest reduction of production together with introducing 'Cap and share' non-debt money and local currencies, work sharing, new forms of property etc. Eco-socialists believe that there is no cure as long as the socioeconomic system remains capitalistic and the growth dogma persist, and therefore they suggest a model of democratic socialism. The Steady State Economy advocates suggest a reduction of the size of population consistent with ecological equilibrium and a good standard of living for all. In achieving these goals, the role of the State is important.

2. The definition of SSE

A Steady State Economy is defined by Daly as

an economy with constant population and constant stock of capital, maintained by a low rate of throughput that is within the regenerative and assimilative capacities of the ecosystem. This means low birth equal to low death rates, and low production equal to low depreciation rates ... Alternatively, and more operationally, we might define the SSE in terms of a constant flow of throughput at a sustainable (low) level, with population and capital stock free to adjust to whatever size can be maintained by the constant throughput that begins with depletion of low-entropy resources and ends with pollution by high-entropy wastes (Daly, 2008).

2 In 2025 the ecological footprint was 2.65 gha per person and biocapacity was 1.49 gha per person. See <https://overshoot.footprintnetwork.org>

In both definitions the key features are stability of population and stability of resource consumption with ecological equilibrium.

In a more recent report (O'Neal et al., 2010: 11) the content of the SSE is expanded to include the following objectives: (a) sustainable scale, i.e. a size that is kept within the capacity of ecosystem to provide resources and absorb the wastes created by production and consumption; (b) efficient allocation of resources; (c) fair distribution in the sense of people having equal opportunities and putting limits to excessive inequality of income; and (d) high quality of life in the sense of having access to health services, wellbeing, leisure time, economic stability etc.

3. Institutions required for SSE

According to Daly (1991):

The kinds of institutions required follow directly from the definition of a SSE: constant stocks of people and artifacts maintained at some chosen, sufficient level by a low rate of throughput. We need (1) an institution for stabilizing population (transferable birth licenses), (2) an institution for stabilizing the stock of physical artifacts and keeping throughput below ecological limits (depletion quotas auctioned by the government) and (3) a distributist institution limiting the degree of inequality in the distribution of constant stocks among the constant population (maximum and minimum limits to personal income and a maximum limit to personal wealth) (p.53)

It is evident from the above that, in the Steady State Economy, the role of government is important. It can change tax rates, intervene in the markets to improve efficiency, impose restrictions on the use of resources when it seems necessary, and keep the population size constant, among other things.

4. Population reduction and age distribution

To keep the analysis simple, let us assume an economy with total population of eighty (million) people equally distributed in four age cohorts, i.e., twenty people are less than twenty years of age, twenty between 21-40, another twenty between 41-60 and another twenty between 61-80. All individuals can enter the labour

market at the age of 21 and necessarily retire at the age of 61. The potential labour force of this economy is forty but some individuals may choose not to work or may be unemployed. The first row of Table 1 shows the initial situation.

Suppose now that somehow this society sees it is overpopulated and decides to reduce total population to 64 million after eighty years when the rate of births and deaths return to equilibrium, by reducing births to sixteen every twenty years. The changes in the age distribution for the next five twenty-year periods are shown in table 1.

Table 1. Hypothetical example of population reduction

Period	Less than 20	21-40	41-60	61-80	Total
1	20	20	20	20	80
2	16	20	20	20	76
3	16	16	20	20	72
4	16	16	16	20	68
5	16	16	16	16	64
6	16	16	16	16	64

In this example, the population is stabilised after eighty years. As this society gradually moves to the desired new population size it experiences a demographic dividend in the second period because the potential labour force exceeds the retired and young people ($40 > 36$) and a deterioration in the dependence-ratio in the fourth period where the opposite takes place ($32 < 36$). In the fifth period the demographic dividend and the deterioration of the dependence ratio both disappear as the total population stabilises to the new level.

5. Economic effects of population reduction

Lower fertility rates and declining population will affect many markets of the economic system, some directly and some indirectly. The main effects of population reduction will appear in the structure of demand, in the labour market, in the reaction of businesses and perhaps in the deterioration of the dependence ratio.

5.1 The structure of demand

Suppose the economy is in the second period where births are reduced from twenty to sixteen. The first effect will be felt by those markets that produce goods and services for children, e.g., medical services, goods for babies and small children, nurseries etc. Slowly the fall in demand will be extended to all the markets that produce goods and services for people below the age of twenty. The result would be a fall in prices and a rise in unemployment. The rise in unemployment should be minor because in the same period job opportunities will be available as some people will retire.

At the same time, the families with a smaller number of children will have to decide how to use the part of their income that now does not have to be spent on their children. Generally speaking, the money that is now available can be either spent on consumption of other goods and services or saved. In the first case, the final result will be a change in the consumption and production patterns in favour of goods preferred by adults. In this case, the choices of parents are important. If the money that is available is spent on material goods such as better clothes, longer vacations etc., the utility level of the family will improve but the long-run effect on the growth of the economy would be immaterial. If the extra money is spent on the education and health of the new generation, the growth prospects of the economy can be greatly improved.

If the part of income now available is saved, the effects will be on the rates of interest and on investment. Interest rates will fall as a result of an increased volume of loanable funds encouraging investment in capital goods.

Thus, it seems reasonable to say that a decline in population will not have negative effects on aggregate demand and, depending on how the income made available from a smaller number of children is used, the economy may grow. This conclusion is valid if it is understood that the population will stabilise at the intended lower level, as shown in Table 1. However, if it is widely expected that birth rates will continue to decline, pessimistic expectations may dominate and lead to economic mild recession. This is more so in cases of investment with long gestation period. Thus, if population reduction is a government project it should be made clear what the target is for the new level of population and also the decline should be gradual.

5.2 *The labour market*

The decline in births will also bring changes in the labour market. On the one hand, mothers with fewer children to raise may enter the labour market sooner and thus increase the supply of labour. On the other hand, the fact that the family disposable income per person increases may give an incentive for some women to withdraw from the labour market. The net effect may be positive or negative and depend on the prevailing culture. In societies with a strong work ethic, it is very likely that the supply of female labour will increase. The effects on male labour supply may be similar and this is more likely to occur in case where people themselves can manage the length of the working day. Thus, the effect on the supply of labour is not clear.

However, in the second period (period 3 of Table 1) the labour market will certainly be affected because the working population will be less, as only sixteen enter the labour market instead of twenty. A smaller labour supply would lead to higher wages. However, this will depend on the extent to which businesses are prepared to reorganise their production process with labour saving technologies.

In periods 3 and 4 of Table 1, the supply of labour follows the decline of population in the two earlier periods. The growth of the economy, measured by the per capita gross domestic product (GDP), depends on the productivity of labour. If labour productivity increases, then GDP and GDP per capita will both increase. If labour productivity remains constant, GDP will decline but GDP per capita will remain constant.

The conclusion to be drawn from this analysis is that the fear that population decline and even declining rates of population growth will be the cause of recession is unfounded. Also, the potential created by the demographic dividend would depend on its use. If it is used for consumption of the generation which first experiences the benefits of a smaller family, there would be no long run benefits for the economy as a whole. If instead it is used for investment in education, skills and good health of the new generation the positive effects will be seen when the new generation enters the labour market.

5.3 *The effect on business firms*

The tendency of wages to increase when the supply of labour declines and the

shortages in the labour market would give strong incentive to business firms to reorganise their methods of production by introducing labour saving technology as they always have done in the past. The development in artificial intelligence will certainly help in that direction.

5.4 The dependency ratio

The dependency ratio deteriorates in periods 3 and 4 of Table 1, from 0.5 (20/40) in period 1 to 0.55 (20/36) in period 2 and 0.625 (20/32) in period 3. It increases to the initial level 0.5 (16/32) in the fifth period. The significance of this decline depends on the earlier use of the demographic dividend. The increase in the dependency ratio does not mean that retired people would necessarily be in a worse economic situation as they may have opportunities to work well beyond official retirement age. Friedman's permanent income theory of consumption and Modigliani's life cycle theory of consumption both suggest that people's life horizon is their expected natural life and therefore they look beyond current income when they decide how to split their current income between consumption and savings. Of course, this requires a sound social security system which may not exist in some countries, particularly in less developed ones.

It is also possible and very likely that, because of higher wages, the revenues of the social security system may increase without raising the percentage of contribution to the social security system. Thus, the worsening of the numerical dependency ratio will not reduce the revenues of the social security system.

Finally, given that the deterioration in the dependency ratio will be only temporary governments may not hesitate to finance the social security system with funds from public debt.

5.5 Other important effects

In addition to the above, there will be important effects on the demand for resources in general. There will be reduced demand for space for houses, schools, highways, airports etc. and the material needed for such purposes.

In big cities, those with millions of people, there will be less traffic, less congestion, less pollution, better police protection and less crime. In less developed countries, the fifteen most populous cities have a total population of 392 million people

and in the developed countries the biggest twelve cities have a total population of 104 million. These are frightening numbers. Also 45 per cent of the world population lives in cities.

It may take decades for these changes to take place but there is no one to blame except ourselves.

6. Income distribution in a SSE

It was mentioned in an earlier section that one of Daly's three institutions of a SSE is a distributive organisation whose function would be to reduce income and wealth differences. The main factors that determine the distribution of incomes and economic inequalities are: (1) material wealth, (2) human capital i.e., education and health, (3) talent and (4) personal preferences.

The strongest determinant of the distribution of incomes in a given society is the distribution of material wealth which is easily transferred from one generation to the next. The first thing that comes to mind regarding income inequality in an SSE is that the stability of population by itself would not allow the formation of huge differences of wealth as is the case today. It is estimated that in some developed countries (USA, Japan, UK, Australia, Canada, Italy and Spain) there were in 2020 821,000 billionaires and 31 million millionaires and in the same year in the same countries there were 119 million people living below the poverty line (Lianos, 2024: 65). Stability of population size at a given level means limitation of accumulation of wealth by the gigantic companies of today as there is a maximum absorption of the products that can be produced by any company and therefore a limitation to its size. Gargantuan companies like Amazon, Facebook, LVMH and many others could not expand to such size in an SSE.

However, government interventions with inheritance and income taxes are usually necessary in order to reduce income inequality and also finance government expenditures. It is often argued that inheritance taxes will reduce the incentive to save and accumulate and thus reduce the formation of material capital; and also that income taxes will reduce the incentive to work and thus reduce the labour force. Both of these effects will have negative results on the production potential of the country. It is probably correct to say that high rates of taxation will negatively affect capital accumulation and labour supply, but the final result

would depend on the height of tax rates. We can safely assume that there are tax rates that would reduce inequalities and increase public revenues without weakening the tendency to accumulate and work. These would be the tax rates that maximise revenues in each case.

Investment in human capital in the form of education and skills and in better health would increase labour productivity and also the adaptability of individuals to new production methods, and thus reduce structural unemployment and raise incomes. Also, better health would increase the number of days at work and reduce medical expenses. In addition to the benefits from the demographic dividend, the State can invest in education, skills and health and thus reduce income inequality.

In my view, every individual is talented in some activity. However, some activities bring more income than others and all talents need hard work and effort to develop. The cultivation of talents should be part of the public educational system in order to give to young people the opportunity to develop their skills and make good use of them, in order to increase their incomes.

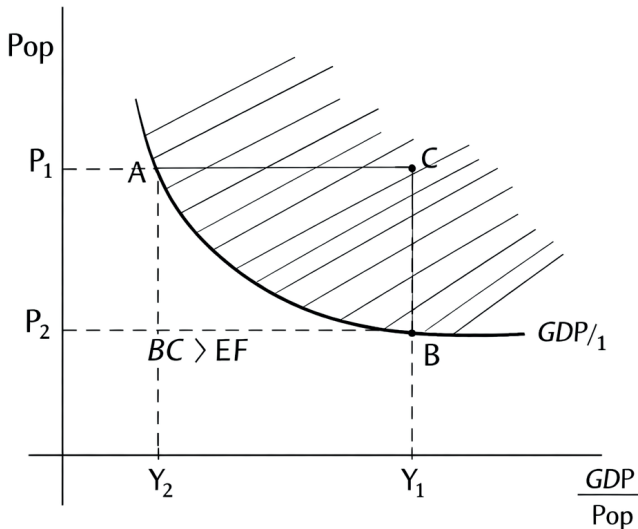
Finally, income differences which are due to personal preferences should not be the concern of the State. If someone prefers more leisure and less income and gets a part-time job when there are vacant full-time jobs with higher income, the resulting income difference is fully justified and no State action is necessary.

7. The budget constraint (or the trade-off between population and per capita product)

The problems we face today as a world society originate from the grave contradiction between the resources of our planet and the demand for these resources. World resources are limited but the demand for resources is unlimited. A useful measure of this inequality is the difference between bio-capacity (BC) and ecological footprint (EF). At the present time the ecological footprint is 178 per cent of bio-capacity. For ecological equilibrium, it is required that $BC=EF$. This means the Earth imposes a budget constraint on the demands of the world population just like family income imposes a budget constraint on how much the family members can spend every period.

If the requirement for ecological equilibrium is satisfied, it also determines the total volume of the product (i.e., GDP) that society can enjoy, given the technology of production. The next step is to decide how much product can be allocated to each individual (or to each family), with a given total product that depends on the number of people (or families). A simple diagram can show clearly the available combinations.

Figure 1. World budget constraint



Suppose that, in a given year, the world product is GDR_1 . The rectangular hyperbola GDP_1 on Figure 1 shows all the possible combinations between the size of population and the per capita product. Obviously, when Y increases, Pop will necessarily be lower. All combinations above the line are infeasible if ecological equilibrium is to be preserved. If the economy reaches a point like point C it means that there is no longer ecological equilibrium. Points below the line are feasible and show a surplus of biocapacity.

In 2023, the world GDP was 106 trillion current dollars. Point C refers to the 2023 world population of 8 billion people and a per capita product of 13230 dollars (106 tr/8 bl). The ecological deficit of 1.1 ($=2.6-1.5$) global hectares is created at this world GDP. It is clear from this figure that the ecological deficit can disappear

by either a reduction of population corresponding to point P1 or by a reduction of per capita product corresponding to point Y2, or of course a reduction of both.

The question that immediately comes to mind is how the choice of the right combination is made – that is, how can we choose the pair of population size and per capita product? We discuss this in a later section in this paper.

The reader may observe that the size of the population and the volume of production are co-determined. As population increases, so does the potential labour force and therefore production. In other words, the budget constraint of the above diagram is invalid because GDP cannot be constant at GDP1 as population changes. The answer to this objection is that, if the other factors of production (capital and land) are constant, the marginal product of labour tends to zero. That is why a small country alone cannot produce the world production of wheat no matter the size of its population. This is the law of diminishing returns. Therefore, when the marginal product labour becomes zero or near zero, production cannot increase by increasing the labour input.

8. The role of technology

In economics, the word technology refers to the ways in which scientific or practical knowledge is applied to the production and consumption of good and services. It refers to the techniques we use to do things. Technology is embodied and disembodied. The tractor with which we plough the land embodies a certain technology. If we use the same knife to trim a pear-tree in a way that produces more pears a disembodied technology is introduced in production.

Technology improves when scientific knowledge advances and shows new ways of producing goods and services. The adoption of new technologies for the production and consumption of commodities depends on the effects this has on the cost of production in real terms i.e., on the quantities of resources required for the production of goods or, in monetary terms, on the cost of production. Technological improvement very often means better quality of product.

Technological progress would increase production with the same resources and therefore the effect on the budget constraint would be a shift of the entire budget line upward to the right.

9. The optimum population size for an SSE

Let us assume that a country with population of a certain size P^* enjoys a standard of living Y^* determined by output per capita GDP^*/P^* . However, the combination (P^*, Y^*) corresponds to ecological deficit because the production of GDP^* creates an ecological footprint greater than the bio-capacity. If the government of this country wants to eliminate the ecological deficit, it must reduce GDP, keeping population at the same size (P^*), or reduce population, keeping GDP at the same level (GDP^*), or reduce both. The available choices are clearly shown in the well-known $I=PAT$ equation where I =impact, P =population size, A =affluence and T =technology.

The variable 'Impact' includes all the direct and indirect effect of production on the environment like CO_2 emissions, melting of glaciers, climate change etc. The variable 'Affluence' means the level of welfare that people enjoy and is approximated by per capita income. Thus, the IPAT equation can be written as

$$I = T \times P \times (GDP/P)$$

This expression makes clear that, given the technology, the impact depends on how many we are on the Earth and how much, on the average, each individual consumes.

The choices available to society – i.e., reducing population or per capita product or both – are difficult because both changes may have negative effects on the utility level enjoyed so far by the population. However, if ecological equilibrium is to be restored, decisions must be made. The first question to be answered is where to start and how far to go. Opinions diverge widely. As we have already mentioned in the introduction (section 1) de-growth theorists would start by reducing production (particularly in the rich countries), eco-modernists and green growth politicians would reject both options and rely on technological improvements of the production methods, eco-socialists would first change the system and transform it to democratic socialism.

The basis of the SSE is the stability of population and at a level that is consistent with ecological equilibrium. Thus, the first step is to find the level of GDP that is consistent with ecological equilibrium. For that purpose, we make the

assumption that the ecological footprint is linearly related to GDP. It follows that the GDP level for equilibrium should be the same proportion of the present GDP as the proportion of bio-capacity to the ecological footprint. In other words, it is assumed that $BC/EF = Y/GDP$, where Y is the production that corresponds to equilibrium and GDP is the current production that has created the ecological footprint. It is estimated that $BC=1.49$ and $EF=2.68$ global hectares per person, respectively, and the world GDP for 2025 in \$US is 114 trillion. Therefore, for ecological equilibrium, production must be reduced to 64 trillion of \$US.

Now we know that, for ecological equilibrium, the multiplication of Population times per capita product must be equal to 64 trillion \$US or less. For this particular time period, the budget constraint that the world society faces is $P \times (GDP/P) = 64$ trillion \$US. Obviously, there is a large number of combinations of P and GDP/P that satisfy the budget constraint. This is society's very crucial and very difficult decision: which combination to choose?

It is my view that we must begin from the choice of the desirable per capita product because that is the basic component of people's welfare. If this is determined, the population size immediately follows. Unfortunately, there is no objective measure of desired level of income since that level may differ among persons and among countries. Useful for our purpose are the ideas of Aristotle and J. S. Mill.

Aristotle believes that a desired level of income is that which allows one to live a good life and good life requires material wealth which would allow individuals 'to live temperately and liberally, for if the two are separated a liberal mode of life is liable to slip into luxury and a temperate one into a life of hardship, since surely these are the only desirable qualities relating to the use of wealth' (Aristotle, 1932: 1265a33-36). Also, '...the best life, whether separately for an individual or collectively for states, is the life conjoined with virtue furnished with sufficient means for taking part in virtuous actions' (Aristotle, 1932: 1323b40-1324a5). However, in addition to arguing for enough material goods, Aristotle suggests that population should not exceed the size above which problems will be created for effective public administration and law enforcement. Also, J.S. Mill favours a population density necessary for obtaining the benefits of co-operation and of social intercourse, but not a population that would be too crowded, because 'It is not good for a man to be kept perforce at all times in the presence of his species'

(Mill, 1970: 115). Of course, there may be other reasons, such as a preference for leisure and socialising, that should be included into the definition of a good life.³

To obtain a feeling of the magnitudes involved, let us take the per capita GDP of the European Union as income that provides the needed resources for living a good life. In 2025 the EU per capita GDP in current \$US was 46,805 and for the same year the equilibrium world GDP was estimated above to 61,253 billion current \$US. Therefore, given the world GDP, the world population should be approximately 1.31 billion people if everybody were to have a good life by European standards. For many people an income of 46,805 \$US per capital exceeds by far the size of an income that satisfies the needs for a good life. It allows luxuries which have no place in the definition of best life. So let consider the case of Greece with per capita GDP of 27,000 current \$US in 2025 which in my experience is enough for one person to have a good life particularly if we take into consideration the economies of size of living in a family. Now everybody on the planet could have a good life if the size of population were 2.27 billion people. Obviously, the present situation (2025) with 8.23 billion people and a world GDP of 114 trillion \$US is not sustainable.

The general conclusion to be drawn from the above discussion and the *grosso modo* estimates is that the world is overpopulated and the combination of its present size with the present level of production is unsustainable. One or the other or both parts of this combination should be limited to much lower size if ecological equilibrium is to be restored.

It is interesting that other empirical studies have come to similar results regarding the optimal size of the world population. Daily, Ehrlich and Ehrlich (1994) estimate the optimum population size on the basis of an estimate of the maximum total world energy production 'at which ecosystems and resources seemed to be holding their own'. Assuming 6 TW total energy production (6,000,000,000,000

3 It is worth citing Bertrand Russell's definition of happiness: 'Certain things are indispensable to the happiness of most men, but those are simple things: food and shelter, health, love, successful work and the respect of one's own herd. To some people parenthood is also important. Where these things are lacking only the exceptional man can achieve happiness, but where they are enjoyed, or can be obtained by will or directed effort, the man who is still unhappy is suffering from some psychological maladjustment...' (Russell, 1930: ch. 17).

watts) and a level of consumption of just 3 kW per person would lead to an optimum population of 2 billion.

The same year, Pimentel et al. (1994), on the basis of an estimate that 0.5 hectare per capita is needed to supply food and assuming a programme of soil conservation, estimated that a world population of 3 billion people could be sustained. Also, Pimentel et al. (2010) have estimated that, under certain reasonable assumptions regarding land inputs, a European standard of living for everyone with sustainable use of natural resources results in a carrying capacity of the Earth of 2 billion people.

More recently, Dasgupta and Dasgupta (2017), using the estimates of ecological footprint relative to bio-capacity and assuming a per capita income of 20,000 international⁴ dollars came to the conclusion that 'maximum sustainable population comes to 3.5 billion'. A few years later Dasgupta et al. (2023), using a global production function and a per capita income of 20,000 international dollars concluded that the sustainable size of the world population is 3.3 billion. Finally, another study, Lianos (2013) estimated that, assuming a per capita income of 11,000 USD (2010, PPP), ecological equilibrium can be maintained if the world population is 2.5 billion or less. Similar results are reported by Lianos and Psiridis (2016).

Clearly, even allowing for a margin of error of fifty per cent, the above estimates show that the present world population size of 8,23 billion exceeds by far the carrying capacity of our planet. The conclusion is that population reduction is a necessary condition for achieving ecological equilibrium.

10. Two comments

1) In the above discussion, we use GDP per capita as measure of affluence as is customary in the literature. However, it is useful to add that not all GDP is available for consumption because part of GDP is devoted to replacement of depreciated capital. A better measure may be the Net domestic product, i.e., $NDP = GDP - \text{depreciation}$.

⁴ Estimates of GDP in international dollars give higher values than estimates in nominal values. For example, the world GDP in 2025 was 114 trillion in nominal values and 162 trillion in international dollars.

- 2) The product per capita (GDP/Pop) is useful but also deceptive. For a country with very rich people and very poor people the average product does not give very useful information. What is important, perhaps more important in some cases, is the distribution of product in the population.

11. How fast can the world population decline?

The size of population changes slowly. The rate of change depends on the total fertility rate and on the death rate. At this time, all countries in Africa and Oceania (with the exception of Australia and New Zealand) and also Central, Western and Southern Asia have TFR that exceed 2.1 and therefore their population increases. Countries in Europe, North America, and Latin America have TFR below 2. China and India, the most populous countries, have TFR 1.02 and 1.94, respectively. Despite the reduction of TFR, the world population is expected to increase to 9.7 billion in 2050 and to 10.2 billion in 2100. In other words, it will take many decades before population begins to decline and more decades to reach a size lower than the present size of 8.2 billion. This very slow process of population reduction immediately raises a crucial question: can we go on for the next hundred years by doing business as usual and, if not, what can we do?

To the first part of this question two answers may be given. First, there is fear that the Earth could not feed more people. A recent FAO study (FAO, 2021: 58) writes

Land and water systems are just managing to meet the demand placed upon them by an increasingly complex global food system driven by unrelenting population growth. There is little room for expanding the area of productive land, yet more than 95 percent of the world's food is produced from land.

Second, there is fear that environmental damage (especially sea level rise, ocean warming and ice sheet melt, ecosystem collapse) may be irreversible on human timescales. In simple words, future generations will have a tough life with poverty, hunger, local conflicts and very likely major wars.

The second part of the question urgently demands an answer. Unfortunately, there are only three ways to avoid the bleak future and all three are difficult to apply. First is the possible improvement of the technology used in production. However,

the environmental problems have been known for at least the last fifty years and, although technology has made progress, it has not helped to the required extent. Second is the reduction of production to about half of the present volume, which will be disastrous given that there are already three billion very poor and hungry people in the world. Third is the reduction of total fertility rates to one child per woman as in China from 1980 to 2015.

Restrictions on family size and particularly to one child per family will be very unpopular and policies for voluntary reduction of population will certainly fail. Persuasion and admonition will not give the needed results if the majority of people do not have the necessary information or if it is against their own interest. Coercive measures in democratic countries will cause demonstrations, unrest and revolutions.

We therefore come to the unpleasant conclusion that human society has trapped itself in a self-destructive trap from which it cannot escape without very significant sacrifices.

12. Is there a way out?

The situation we are in today reminds me of a similar situation in the ancient Greek history. In 480BC, Athenians asked the Oracle of Delphi what to do to counteract the huge Persian campaign against them. The Oracle's answer was 'Every man for himself'. The Greeks did not follow the Oracle's advice but united destroyed the Persian army. This is an early and valuable lesson – that people, when united by common purpose, are capable of great things.

I have argued above that the only way to solve the expected global crisis is by reducing the total fertility rate to one child. The only case where a coercive policy of one child has a chance to give the needed results is if there is a credible universal agreement that will include at least the following terms: (a) local and regional wars will be immediately terminated, (b) the international order will not be disturbed and (c) there will be significant income transfers to countries that will be seriously affected by the reduction of family size. These are the countries that have organised their economy and social life on the basis of large families.

Such a plan may appear to be unreasonably optimistic but we will not know until we try it.

Appendix: Ecological equilibrium

An ecosystem is defined as an area where animals, plants and other organisms coexist and interact among themselves and also with non-living elements (water, sunlight, soil, etc.) All the parts of an ecosystem depend on each other and thus a change in one part can have minor or major effects on the whole ecosystem.

We can think of an ecosystem as a system of mathematical equations where the change in the value of any variable changes the equilibrium values of some or all other variables.

An ecosystem is in equilibrium when all its parts are in balance with each other. It may remain in equilibrium as long as resources and proper condition are available for all living organisms. Equilibrium may be disrupted when there is a loss of the available resources or a negative change in living conditions (e.g., forest fires, increasing temperature etc.).

Earth, the planet on which we live, can be thought of as a huge ecosystem including humans. Given the way that humans have behaved at least for the last 12,000 years, since they began to cultivate the land, it is obvious that the ecosystem 'Earth' will never be in equilibrium. The main disequilibrium that we have observed for centuries and more so during the last century is between the needs of humans and the resources to satisfy those needs. At any period of time, the needs of humans are the equal to the product of the size of population times the per capita resources needed.

The resources necessary for the satisfaction of needs depend on the size of population, the consumption per capita and the available technology for production and consumption of goods. Therefore, as long as there is an increasing demand for resources to be used for satisfaction of human needs, leading to increasing intervention in nature's condition, the global ecosystem will be in continuous disequilibrium.

A satisfactory measure of the global disequilibrium is the difference between bio-capacity (BC) and ecological footprint (EF). Ecological equilibrium exists when the ecological footprint is equal or less than the bio-capacity. The satisfaction of this condition can be achieved at many volumes of economic production, e.g., at

various sizes of world Gross Domestic Product (GDP). For a given bio-capacity, there are many GDP levels at which EF is less than BC and at any given time only one GDP with ecological footprint equal to bio-capacity. Modern societies try to achieve maximum GDP because it is generally believed that economic welfare makes people happy. Thus, the maximum size of a SSE should be that at which $BC=EF$.

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