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Julio A. Gonzalo and Félix F. Muñoz

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Prospects of world population decline in the near future: a short note

Julio A. GONZALO[1] & Félix-Fernando MUÑOZ[2(*)]

Abstract: An article in Science (4 November 1960) proposed Friday 13 November AD 2026 as the "Doomsday" of planet Earth, a doomsday produced by the "world population" going to infinity. In that paper, a rudimentary rate equation describing the evolution of the world population with time, was approximated in such a way that a quantitative calculation produced that particular date. In this note, we give a more realistic rate equation which respects general conservation principles and we compare previous results and the results of our calculation, with actual UN data for 1960-2010 and UN medium term projections. At present there is disagreement among experts as to what can be expected for the world population in the future. Some think that the population is still growing out control, some say it will be approximating a constant level by 2050, whilst others expect it to be clearly in decline somewhere between 2050 and the end of 21st century. Our model shows conclusively that if no drastic and unexpected changes take place soon, the world population will be decreasing at an accelerated rate after 2050. Our rate equation approach is similar to that used in condensed matter physics and chemical physics to describe the evolution of a two level system under an external perturbation. The result is much more realistic than a purely exponential result as has been generally assumed in the last decades of the last century.

Keywords: world population decline, improved rate equations

1. Department of Materials Physics, C-04. Faculty of Science. Universidad Autónoma de Madrid. Madrid, SPAIN. E-mail: julio.gonzalo@uam.es

2. Department of Economic Analysis: Economic Theory and Economic History, E-1-310. Universidad Autónoma de Madrid. Madrid, SPAIN. E-mail: felix.munoz@uam.es

(*) Corresponding author. Adress: Facultad de Ciencias Economicas y Empresariales. Universidad Autónoma de Madrid. C/ Francisco Tomás y Valiente 5. 28049. Madrid. SPAIN.

Tel.: (+34) 91 497 43 95 / Fax: (+34) 91 497 70 69

Prospects of world population decline in the near future: a short note

'Doomsday: Friday, 13 November, A.D. 2026.' This was the original title of an article published in *Science* (4 November 1960) by Heinz von Foester, Patricia M. Mora and Lawrence W. Amiot.[1] They warned in the article's subtitle that at this date the human population will approach infinity if it continues to grow at the same rate as it has in the last two millennia. The authors begin by arguing that in any biological system the time evolution of the total population is determined by two factors: fertility and mortality, and that the rate of change should be given by:

$$\frac{dN}{dt} = \gamma_0 N - \theta_0 N = \alpha_0 N \qquad (1)$$

Where each element displays a fertility of γ_0 offspring per element, per unit of time, and has a mortality $\theta_0 = 1/t_m$ derived from the life span of an individual element of t_m units of time. Thus, $\alpha_0 = \gamma_0 - \theta_0$ may be called the 'productivity' of the individual element [1: 1291]. This equation results for α_0 = constant, in an exponential (Malthusian) increase for any $\alpha_0 > 0$. The authors then consider the case of a 'hypothetical paradise' in which no environmental hazards, no limited food supply, and no detrimental interactions between the individual members of the population need to be taken into consideration. This is of course, not very realistic, and so they proceed to relax the assumption of α_0 constant and, somewhat arbitrarily, they assume the productivity α changing as a function of N as:

$$\alpha = \alpha_0 N^{1/K} \qquad (2)$$

where α_0 and K can be fitted to the available experimental data for the human population in an extended time interval. Their approach leads to:

$$N(t) = K / (t_0 - t)^n \qquad (3)$$

where K, t_0 and n are adjusted to the available world population data. K has the meaning of a population number at $(t_0 - t) = 1$ measured (arbitrarily) in years, t_0 is the so called 'doomsday time' and n is a dimensionless exponent that, using their chosen set of data, comes close to one. Obviously, Eq. (3) blows up at $t = t_0$ for any $n > 0$.

This approach does not follow the laws of physics. The total mass upon the Earth surface is strictly conserved. It cannot grow. Total biomass can grow, but always within definite limits (and much less grow to infinity). Furthermore, von Foester, Mora and Amiot estimate K, t_0, and n for the human world population as $K = 1.79\times10^{11}$, $t_0 = 2026.87 \pm 5.5$ years (which can be approximated as 2026), and $n = 0.99$. Using these data in Eq. (3), implies that $N(1960) = 2.82\times10^9$, somewhat lower that the UN estimate for that year, $N_{\mathrm{UN}}(1960) \approx 3.02 \times 10^9$. However, by substituting $K = 1.91 \times 10^{11}$ for $K = 1.79 \times 10^{11}$, this difference can be corrected.

Figure 1 gives, in the same log-log representation as used by von Foester, Mora and Amiot, ($\log_{10} N(t)$ vs. $\log_{10} N(K/(t_0\text{-}t))$, the time evolution of the total world population from before 1960 to the years beyond 2010. It can be seen that the UN data correlate well with the 'doomsday' curve from 1960 to 1990, but thereafter begin to deviate substantially. By 2010 the value for $[P(t)]_{vF}$, as estimated by von Foester, Mora and Amiot, is about 444 times larger than the actual $[P(t)]_{UN}$ value for that year. In the final paragraph of their paper, the authors describe some of the suggestions that have been proposed to solve the problem of the predicted world population explosion. These suggestions include legislation, for example, heavy taxation of families with more than two children and even *space travel* [2] -although the authors point out that no re-entry permit to Earth can be granted to those leaving the planet.

About forty years later Lutz, Sanderson, and Scherbov, [3] published an article in *Nature* entitled 'The end of world population growth' in which they conclude that this growth is likely to cease in the foreseeable future. They improve on the earlier methods of probabilistic forecasting and show that there is about an 85 per cent chance that the world's population will stop growing before the end of the century, a 60 per cent chance that it will not exceed 10 billion people before 2100, and a 15 per cent chance that it will be less at the end of the century than at the beginning. They also conclude that there is a 20 per cent chance that the population will reach its peak by 2050.

As can be seen below, using both an *improved rate equations* (*IRE*) model, and the additional actual world population data for 2001-2013, enables us to conclude that it is likely (a likelihood substantially higher than 20 per cent) that the maximum (not a peak) in world population would occur around 2045.

Figure 2 gives the UN estimated total world population, in billions, for the years 2010-2100 for the high, medium, and low fertility variant scenarios (see UN, 2013). The actual data for 2010 and the *IRE* projections (see below) for 2010-2040 (open circles) are also given. It can be seen that historically the low fertility variant UN scenario fits better than the medium UN scenario with the actual data for 2000-2010 and is closer to the *IRE* projection for 2000-2040.

Lutz, Sanderson and Scherbov also examine regional population trends. They conclude that the extent of the regional differences in the speed of population ageing, concomitant with population stabilization and decline, will pose major social and economic challenges. They further state that the prospect of an end to population growth is welcome news for efforts being made towards a sustainable development, but this conclusion is far from substantiated as the recent global economic crisis clearly suggests. They also say that the main determinant in the timing of the 'pick' in population size is the assumed speed of fertility in the past when fertility was higher than it is today. However, it should be noted that the spectacular increase in the world population in the second half of the 20th century was mainly due to a sustained increase in *life expectancy* rather than to an increase in fertility, which has been continuously decreasing since the early fifties.

In this paper we propose a novel rate equations approach to model world population trends.[4] This approach is designed to describe *steps* up or down in the population in a *two level system* (individuals in level (2) *actually alive*; individuals in level (1) or *potentially alive* in the relative abundant available biomass). It should be noted that the terrestrial ecosystem is a closed one. There is a finite amount of total biomass; the total mass of the human population is, of course, conditioned by this total biomass. We assume as a first approximation that the fraction of total biomass which is susceptible to transform into a living human population, or potentially alive human population, is approximately constant for a step up or down in human population

The rate equations are:

$$\frac{dN_2}{dt} = N_1 p_{12} - N_2 p_{21} \qquad (4)$$

$$\frac{dN_1}{dt} = -N_1 p_{12} + N_2 p_{21} \qquad (5)$$

resulting in:

$$\frac{d\left(N_2 - N_1\right)}{dt} = \left(N_1 + N_2\right)\left(p_{12} - p_{21}\right) - \left(N_2 - N_1\right)\left(p_{12} + p_{21}\right) \qquad (6)$$

Where $(N_1 + N_2) = N$ is related to the maximum jump in population ΔP_{max}, $(N_2 - N_1)$ is related to the actual change in population at time t, $\Delta P(t)$, at which $N_2 = N_2(t)$ and $N_1 = N_1(t)$, and p_{12} are directly related to the birth rate r_b, and p_{21} to the death rate r_d. Two important dynamic parameters, $\alpha = \frac{1}{2} Ln\left(r_b / r_d\right)$ (dimensionless) and $\tau = \left(r_b \times r_d\right)^{-1/2}$ (a dimension of time) are defined. A general solution of Eq. (6) leads to:

$$P(t) = P_{RL} + [\Delta P_{\max} \times \tanh\alpha]\left[1 - e^{-(t-t_i)/\tau}\right] \quad (7)$$

Where P_{RL} is the population at replacement level before the jump, t_i is the inflection time for a jump in population (we are considering here a jump up) and τ is a characteristic time, related to the effective fertility time span in the female population which comprise approximately one half of the total human population.

Eq. (7) can be conveniently rewritten taking into account that for a well-defined jump in population $P(t)$ first grows gradually from P_{RL} towards $P_{RL} + \frac{1}{2}[\Delta P_{\max} \times \tanh\alpha]$ and then grows gradually from this population to $P_{RL} + [\Delta P_{\max} \times \tanh\alpha]$ (for details see [5]), as given by:

$$P(t) = P_{RL} + \frac{1}{2}[\Delta P_{\max} \times \tanh\alpha]\left[1 + \tanh\frac{t - t_i^*}{\tau^*}\right] \quad (8)$$

A good fit to the UN data is obtained with P_{RL} = 2 billion, $\Delta P_{\max} \times \tanh\alpha$ = 2.93 billion, and t_i^* = 1985 and τ^* = 30 years have been chosen for an optimal adjust to the actual population series. This is what we have called the improved rate equations (*IRE*) solution for our model, describing in this case the time evolution of world population for a population jump up.

Before using Eq. (8) to analyse population data and to make momentum-like projections for the near future, let us look at the trend in the annual relative increase in world population $\Delta P(t)/P(t)$ (per cent per year) as a function of time. Figure 3 gives the actual UN population increase rate for 1950-2010, the revised UN population increase rate for 2013-2040, as well as the increase rate obtained using Eq. (8).

By extrapolating linearly from 1990 forward, the UN data, $\Delta P(t)/P(t)$ becomes zero at about $t = 2045 \pm 16$. At this time the world population must go through a transient maximum of about 7.75 billion. Thereafter, if the birth rate continues to decrease, and the death rate (concomitant with a decrease in the average life expectancy due to overall ageing of the population as a whole) decreases also, the overall decrease in world population becomes something to be anticipated.

Finally, Figure 4 shows the UN world population data (crosses) for 1950-2010 and the world population projections obtained using Eq. (8), the *IRE* solution (open circles), for 2015-2040. We can see that the *IRE* solution fits the data very well. The graph also shows that the UN estimation projections for the world population in 2010, made during the period from 1990 to 1998 where substantially higher than the actual value in 2010, with the estimates decreasing gradually as they neared 2010. The UN overestimations of the future world population for 2020 and 2030 in previous decades seem to be negligible if $P(t)$ calculated using Eq. (8) is correct.

Of course, no statistical model can predict changes in global socio-cultural trends. But the short and medium term projections based upon the use of our *IRE* model, which properly accounts for the role of momentum, may be used to sound the alarm about the looming decline in population in the second half of this century. It may also prepare the ground among economists, sociologists, and politicians to face up to the inevitable and as yet unknown consequences.

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Dataset: United Nations, Department of Economic and Social Affairs, Population Division (2013). World Population Prospects: The 2012 Revision, DVD Edition.

Figures

Figure 1: World population trends

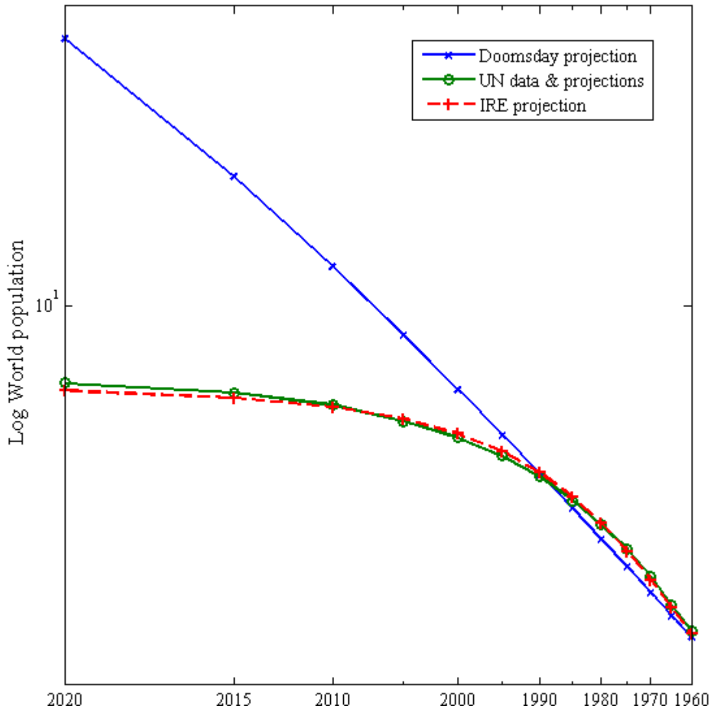
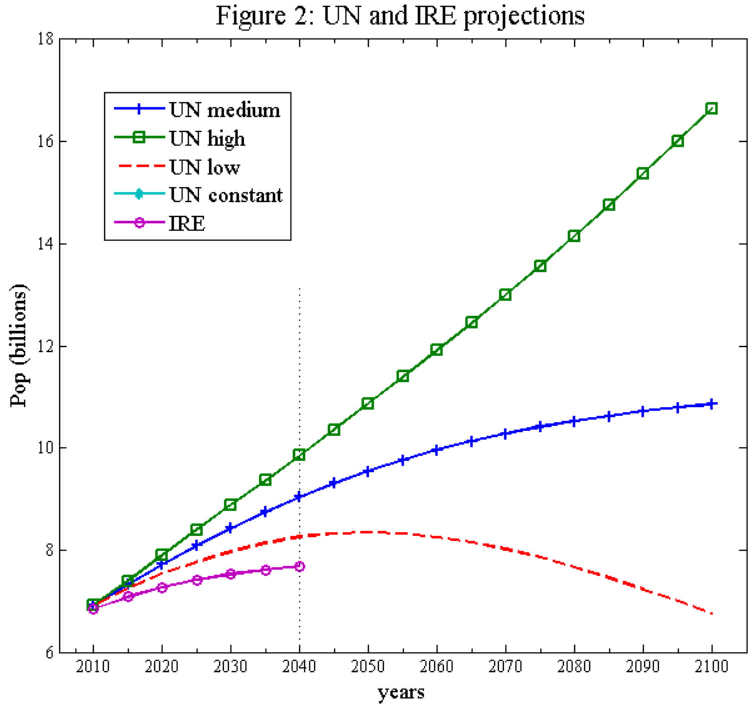


Figure 2: UN and IRE projections



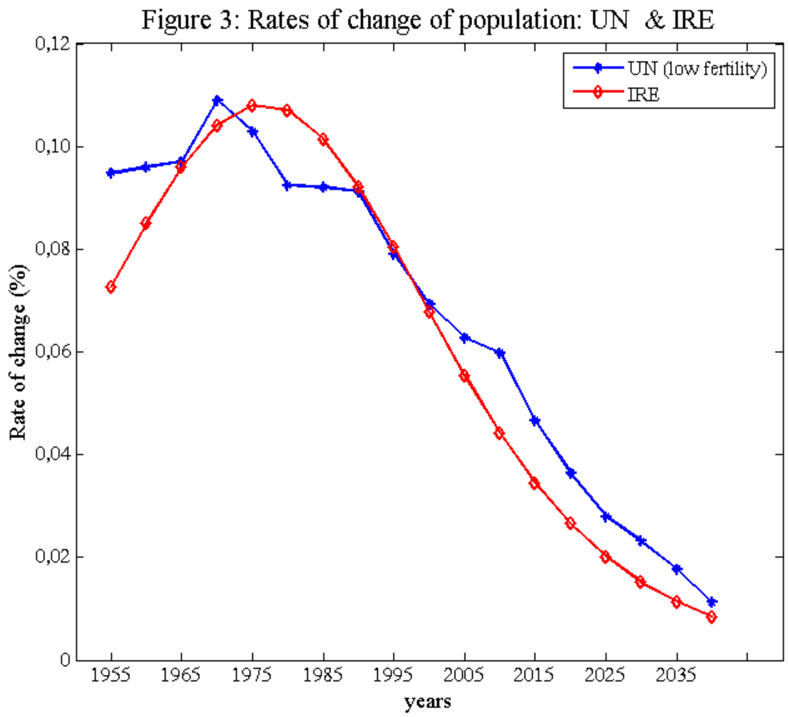


Figure 3: Rates of change of population: UN & IRE
UN (low fertility)
IRE
Rate of change (%)
0,12
0,10
0,08
0,06
0,04
0,02
0
1955
1965
1975
1985
1995
2005
2015
2025
2035
years

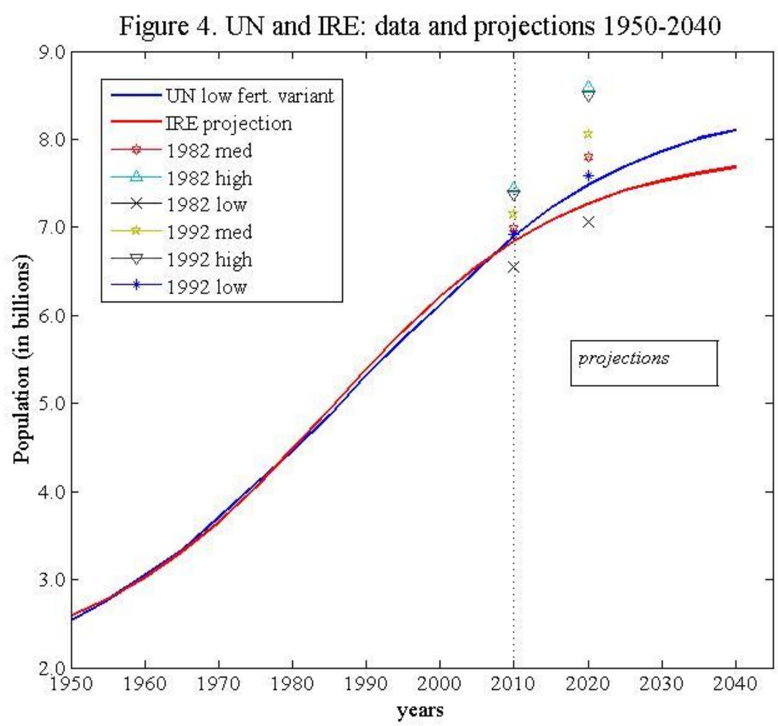


Figure 4. UN and IRE: data and projections 1950-2040
UN low fert. variant
IRE projection
1982 med
1982 high
1982 low
1992 med
1992 high
1992 low
projections
Population (in billions)
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1950
1960
1970
1980
1990
2000
2010
2020
2030
2040
years