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Population and economic development: A counterintuitive relationship for a sustainable world

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ABSTRACT

The world population continues to grow, generating a rapid consumption of the earth's resources that do not have enough time to regenerate. On one side, some economists warn about restricting the population increase that penalizes countries favoring birth control. Conversely, the widespread way of thinking pushing toward galloping demography can be uneconomic. Is the straight correlation between solid demographics and high economic growth correct in a complex and highly nonlinear system? Is the assumption behind the quasi-postulate indicating infinite growth true? This paper attempts to explain the divergent viewpoints regarding the impact of population size on economic development by offering a holistic model instead of a linear cause-and-effect analysis and its variations we find in the majority of works on the subject that neglect the higher-order interactions between various factors, generating approximate, even biased answers due to a legitimate desire to simplify complex phenomena. A systemic model integrating population growth, technology, and economy in a fully endogenous way and in a finite world is proposed, simultaneously highlighting sustainability's role through two main variables, namely "Population" and "Carrying Capacity" of earth. The model tries to find the right balance between those, alarmists, who advocate a soon uncontrolled situation, and others, easygoing, and warn against any drastic form of growth limitation susceptible to plunging billions of people into poverty. It contributes to establishing the conditions for preserving the environment while stimulating the economy in a sustainable manner, with population evolution in the foreground.

1. Introduction

Demography accompanies economic growth. This statement is taken up in concert by some economists, politicians, and authors while the debate between population growth and economic development is not closed in the specialized fora (Yaya et al., 2021). In fact, "Mathematical demography is concerned with commonsense questions about, for instance, the effect of a lowered death rate on the proportion of old people or the effect of abortions on the birth rate. The answers that it reaches are not always commonsense, and we will meet instances in which intuition has to be adjusted to accord with what mathematics shows to be the case. Even when the intuitive answer gives the right direction of an effect, technical analysis is still needed to estimate its amount." (Keyfitz and Caswell, 2005).

Indeed, if we compare the statistics of economic growth and that of demography, we see a strong correlation: The increase in the world population has led to an increase in the average standard of living with of course strong disparities.

Explanations are clear: A dominant young population implies a larger workforce and an increased consumption need. In addition, young people promote economic dynamism through innovation and the search for new products.

In general, population growth causes accelerated urbanization of the planet: In 1960, there were about 300 million city dwellers in large cities while, in 2021, they are nearly 2.5 billion more than 4 billion people in urban areas.

These trends will have serious geopolitical consequences: Asia and Latin America, initially, Africa secondly, will embody the real potential of the planet if the demographic window of opportunity (Crombach and Smits, 2022) for achieving growth is

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correctly exploited. For instance, in 1913, Europe was more populated than China; in 2010, China represents twice Europe, which will represent only 6% of the world population in 2030 (against 15% for China)! Moreover, after the famous one-child policy, China now allows a second and even a third child taking into account its negative impact on social and economic outcomes, while the long-term effects remain under-analyzed (Huang, 2017; Zhang, 2017).

In 1950, the whole of "the West" (Europe, United States) provided 68% of world GDP, against 30% expected in 2030, according to World Bank forecasts.

Can we therefore simply encourage a natalist policy to halt the announced decline of the Western-assimilated world while hoping political governance will not waste the fruits of this growth by sterile actions or initiatives? Can we see here an opportunity for developing countries and countries in transition, which have a high birth rate? This question was treated by several authors such as Jafrin et al. (2021) who highlighted that appropriate policies need to be defined and adopted in order to strengthen the considerable benefits of demographic dividend on economic growth; the workforce is at least almost utilized.

Is the straight correlation between strong demographics and high economic growth correct in a complex, hyperchaotic, and highly nonlinear system? Is the basic assumption behind the quasi-postulate, indirectly indicating infinite growth, true? Do we not risk exceeding the carrying capacity of the planet, highlighting “The Tragedy of the Commons” of Hardin (1968) and the “Limits to Growth” according to Meadows et al. (1972, 2004)?

This paper will attempt to question the hypothesis of linearity, largely accepted through the correlation made between the macro-variables "demography," on one side, and "economic growth," on the other side.

2. Literature review and relationships between demography, sustainability, and economic development

The population is one element of a larger system, the social system, based on historical paradigms that have notably shaped population policies and programs not only in the past but also today (Charbit, 2022). Its growth is influenced by some parameters such as socioeconomic variables, education, technology, and ideology in some cases (Johnston, 2021).

A large population in a country could bring a heavy burden on society. It should limit the development rate of the country, namely negatively impacting the economy, education, and improvement in science and technology (Foley, 2000).

Note these elements and population are in fact in mutual causality, generating feedback links between them. However, most demographic models assume that the main variables such as fertility, births, net migration, and mortality, to name only these, are exogenous and continue to calculate on this basis the resulting age distributions and total populations. Nevertheless, over longer time horizons, births, and life expectancy should not be treated as exogenous elements as indicated by Heintz and Folbre (2022) in their article where they proposed a model dealing with fertility as an endogenous parameter and taking into account different demographic regimes, which highlights the fact that demographic trends affect macroeconomic results and reciprocally. Factors such as nutrition, access to health care, and comfort have to be considered. They should be impacted by the size and wealth of the population, following a great number of feedbacks.

Forrester (1971) and Meadows et al. (1974, 2004) developed the first integrated models of world population, the global economy, and the environment. These models were designed to investigate the effects of population and economic growth as human activity converges towards the carrying capacity of the earth, which is the population that can just be supported by the environment.

Meadows et al. (2004) sought to model the demographic transition (Fig. 1) that describes the pattern of change in population growth rates as nations industrialize. Consequently, during the demographic transition, population growth sharply accelerates since death rates fall, while birth rates remain high. Eventually, fertility falls into a rough balance with mortality and the population approaches equilibrium.

Fig. 2 shows the evolution of the Moroccan, Egyptian, and Swedish total population between 1960 and 2019, highlighting stage 4 of the Demographic Transition Model (DTM) for Sweden, stage 3 for Morocco, and stage 2 for Egypt due to the high birth rates and low death rates, meaning that the Rate of Natural Increase (RNI) -which is a proxy of how quickly a population is increasing or declining- is growing and the country has yet to industrialize according to DTM. If Egypt were to industrialize, the RNI would decrease, preventing overpopulation and other problems in the future.

Considering this finding, the DTM model is based on the fact that there is a clear relationship between birth and death rates that has an impact on the level of industrialization and economic development of a country, which was also highlighted by Bairoliya and Miller (2021) for China and by Chaurasia (2021) in his comparison between China and India using data for the 1990-2018 period.

More specifically, Fig. 3 shows “birth and death rates for Sweden and Egypt. In Sweden for instance, where industrialization began early, death rates fell slowly, so population growth was modest during the transition while, in Egypt, as in many developing nations, the death rate fell sharply with relatively correct public health and the birth rate, while starting to fall, remains high, so population growth is very rapid” (Sterman, 2017).

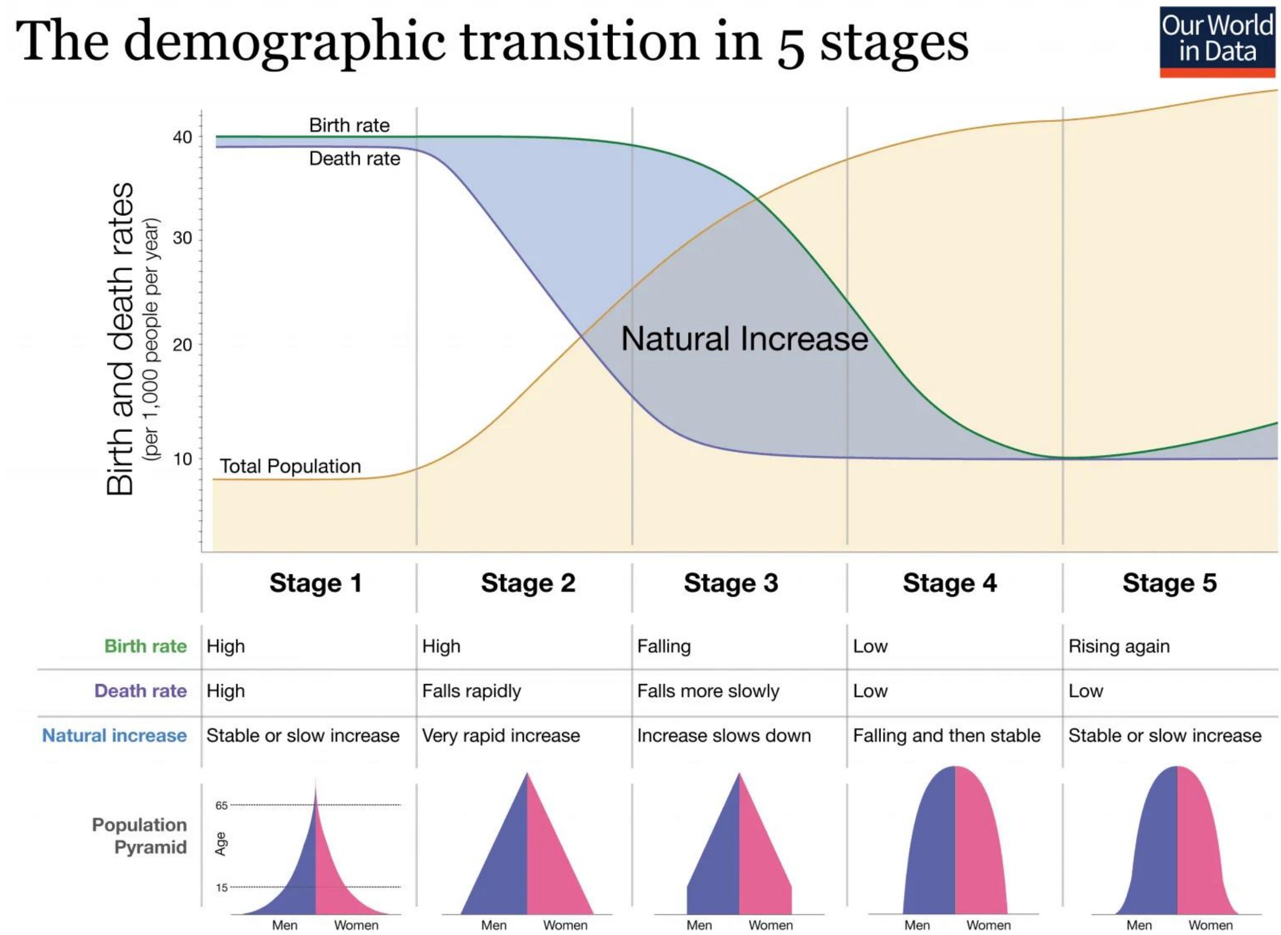


Fig. 1: The demographic transition in 5 stages (www.ourworldindata.org)

For Morocco, the situation is between Sweden and Egypt, although somewhat closer to Sweden. A decrease in the fertility rate is observed in Morocco as namely the result of societal ideals evolving around contraception and the status of women. The penetration of women into the workforce has led to a decrease in the birth rate over the last decades. Death rates have to be affected by continued advances in medicine and public health. Still, while the declining death rate was the core element in Stage 2 of DTM, the declining birth rate is the primary variable in Stage 3 and the decline could greatly be attributed to the increase in the economic and social mobility of the population.

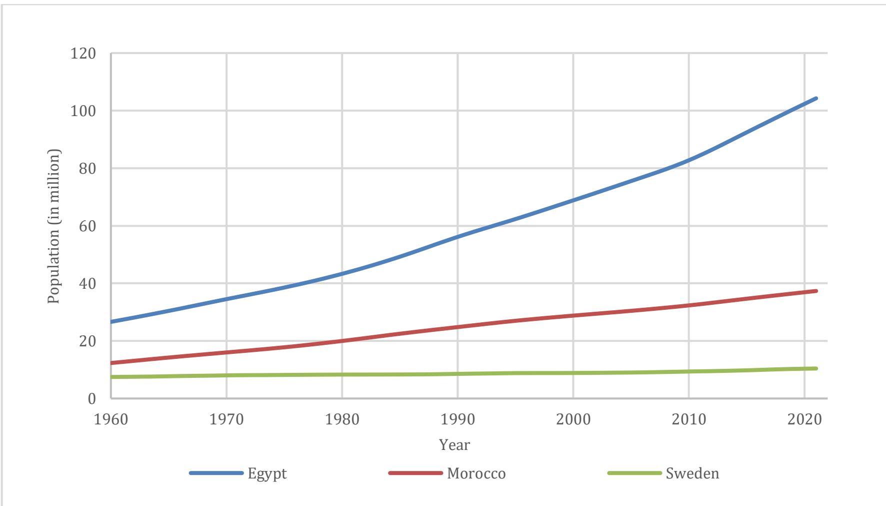


Fig. 2: Total population-Sweden, Morocco, and Egypt (www.data.worldbank.org)

Consequently, to manage population growth, society must be taken as a whole to be studied, highlighting the social elements in the system that have a close bearing on population growth and are the causes that stimulate rapid population growth. In this framework, relationships between these elements and population growth have to be analyzed, making use of the system dynamics theory and executing simulations that generate a group of results allowing to outline of a clearer vision for a better understanding of the population growth and the economic development mechanisms.

The objective will be to find a genuine equilibrium between a significant growth of population with its negative consequences and a sharp decrease in population size that can destabilize governments' commitments to maintain services and infrastructure.

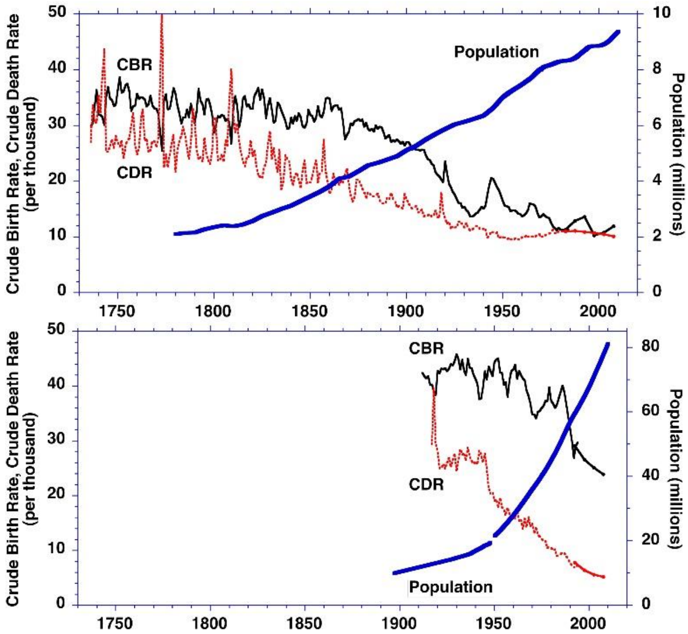


Fig. 3: Sweden versus Egypt: The demographic transition (Sterman, 2017)

In this framework, Benmoussa (2020) based on Sterman's (2014) work, has developed scenarios and performed an analysis based on a model taking simultaneously into account growth, earth's carrying capacity, and technology by integrating feedback, time delays, and stock-flow structures, yielding a conceptual framework able to identify the key leverage points for a sustainable world (Fig. 4).

The main qualitative result has consisted of the human activity growth that has to be gradual and smooth, converging towards a stable equilibrium in order to preserve the earth's carrying capacity, avoiding the traps of the tragedy of the commons (Hardin, 1968), the economic decline that could be disastrous, as depicted in Fig. 5, and cultivating the nexus between green investment, natural resources, technology innovation, and economic growth (Zhang et al., 2022).

Therefore, the proposed model (Fig. 4) has helped to understand the fundamental structure of the system in which individuals evolve and to pinpoint the critical variables that are able to fix the problem of sustainability. Regulation of growth intensity, monitoring of regeneration capability, and simply the fact to gradually, but seriously stop the use of non-renewable resources, are the main factors to closely watch. For sure, technology cannot indefinitely push the boundaries of unrestrained exploitation of our resources, if only because of the time lag between the technology deployment and the disastrous effects exercised on a planet with limited resources. Note also that even for renewable resources, there are limits to regeneration and restoration.

More accurately, what are the social factors in a system that have a close bearing on population increase? How can we use them to define a demographic model linked to the carrying capacity of the earth for a sustainable world without compromising economic development (Taagepera, 2014; Meyer and Ausubel, 1999)?

3. Causes of rapid population growth

3.1. Macro-causes

It is obvious that real causes have to be identified in order to seize adequate measures allowing to accurately understand the mechanisms behind the population growth for finding out what steps and policies should be adopted to better manage the drivers of demographic growth.

In the social system, some elements have a direct bearing on the population as in Fig. 6. They form a subsystem, highlighting non-linear links between the economic level of a country, its general level of education, its policies, and its positioning in science and technology.

Suppose the birth rate is y and the macro contributing elements (economic level, level of education, and factors of policy) are x_i, then the relationship is simply as Eq. 1:

$$y = \alpha\, exp\left(\beta \sum_{i=1}^{3} x_i\right), \tag{1}$$

where, α and β are coefficients to determine.

This utility function will then demonstrate that there exist links between at least these three elements and population growth. In fact, the other elements in Fig. 6 also bear some relation to the birth rate, as well as several micro-causes we will identify hereinafter.

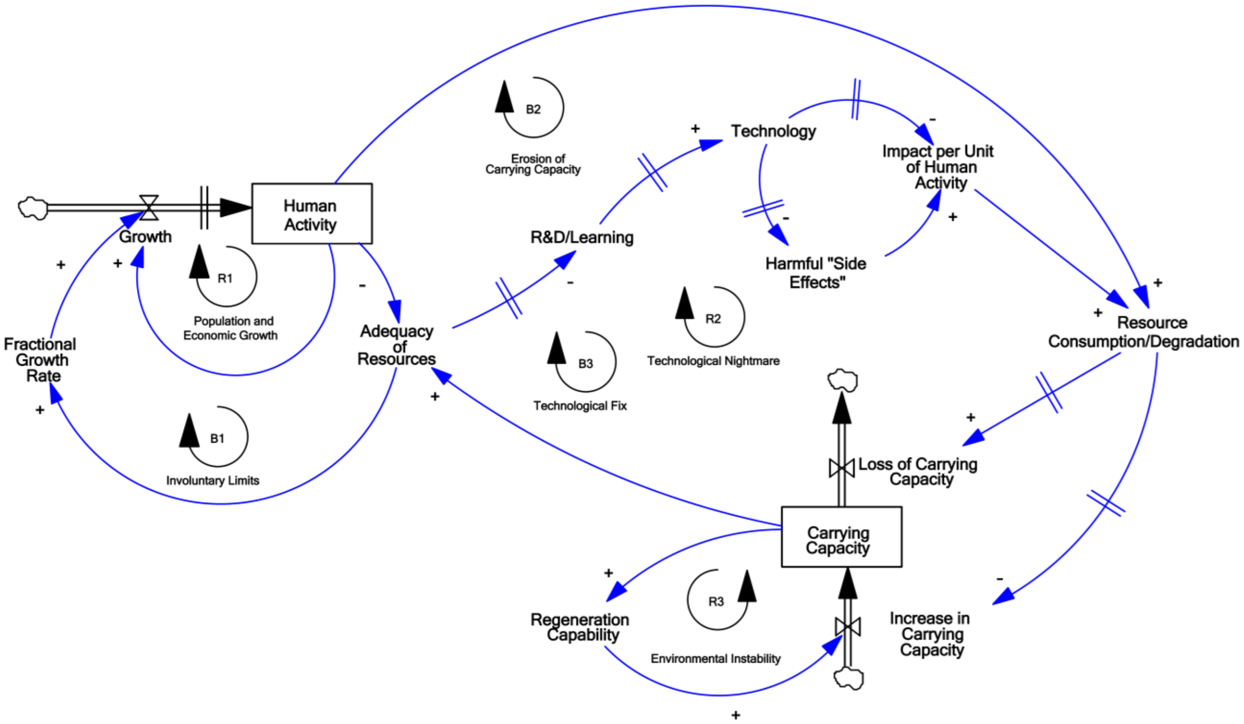


Fig. 4: Integrating growth, carrying capacity, and technology (Sterman, 2014)

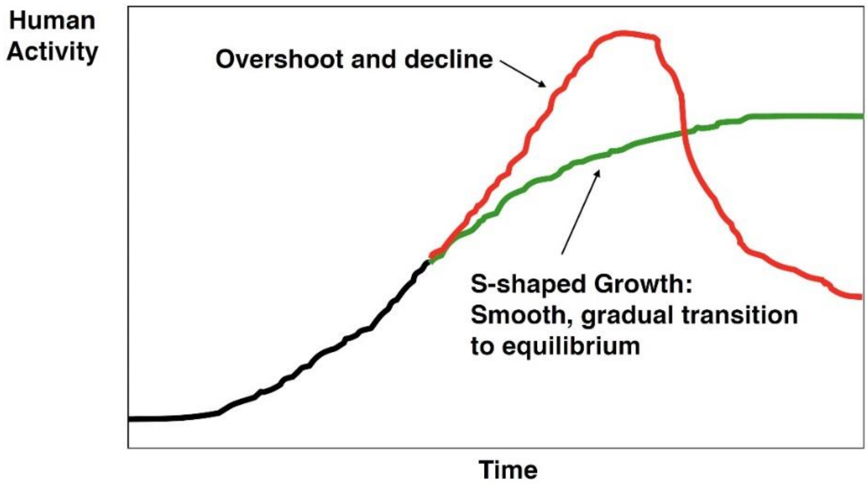


Fig. 5: Possible futures: Decline or an s-shaped growth (Benmoussa, 2020)

3.2. Micro-causes

In order to identify the drivers of population growth, we should consider more tangible causes from literature (Warfield, 1989) that we can group into different categories used in the system dynamics model we propose in this paper.

These factors, directly or indirectly considered in our system structure model, are mainly as follows:

- Population
- Birth rate
- Multi-birth childbearing
- Early marriage child-bearing
- Illegitimacy
- Desire to have boy babies
- Supporting old people
- Women work
- Ancestral influence
- Quality of public health
- Age structure of the population
- Family income
- Scientific and technological level of the environment in which we operate
- Socioeconomic level of the society
- Universal cultural education.

Note these different elements, in a macroscopic framework, have to be considered taking into account the earth's dynamic carrying capacity which is defined as the evolving "size of the population the habitat of that species can sustainably support" (Wackernagel et al., 2002).

4. System dynamics in action

4.1. Modeling demography and carrying capacity

Based on the different points and analysis made above, following the work of Sterman (2012), Meadows et al. (2004, 1974), and Forrester (1971), a global model including interactions of population and the environment (then economic growth) in a fully endogenous fashion and in a finite world is proposed. Therefore, in addition to flows and links, relationships between two stocks that are “Population” and “Carrying Capacity” of the earth are introduced (Fig. 7).

Appendix A defines all the variables used and the different mathematical formulas characterizing the model’s variables. Qualitatively, Fig. 7 shows that as population (and then economic activity) grows relative to carrying capacity, the adequacy of resources declines. The sufficient decline in resource adequacy is able to lower the net fractional growth rate in human activity, causing growth to stop via “Limits to Growth.” Consequently, it remains evident that an equilibrium has to be found between population growth and the dynamic earth’s carrying capacity for sustainable economic growth, expanding the classic Malthusian theory. In fact, the “Smithian (after Adam Smith) baseline shows that capital distribution replaces population distribution as a mechanism of growth, inducing a radical change in the concept of the population” according to Thomas Robert Malthus (Kreager, 2022; 2017; 2015).

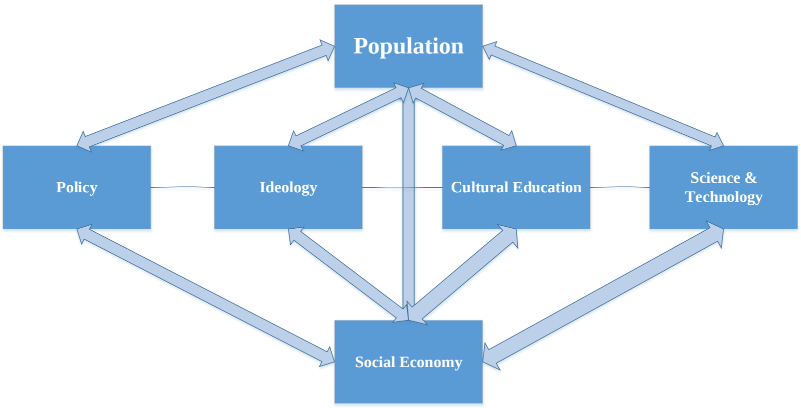


Fig. 6: Causal links between population and social system

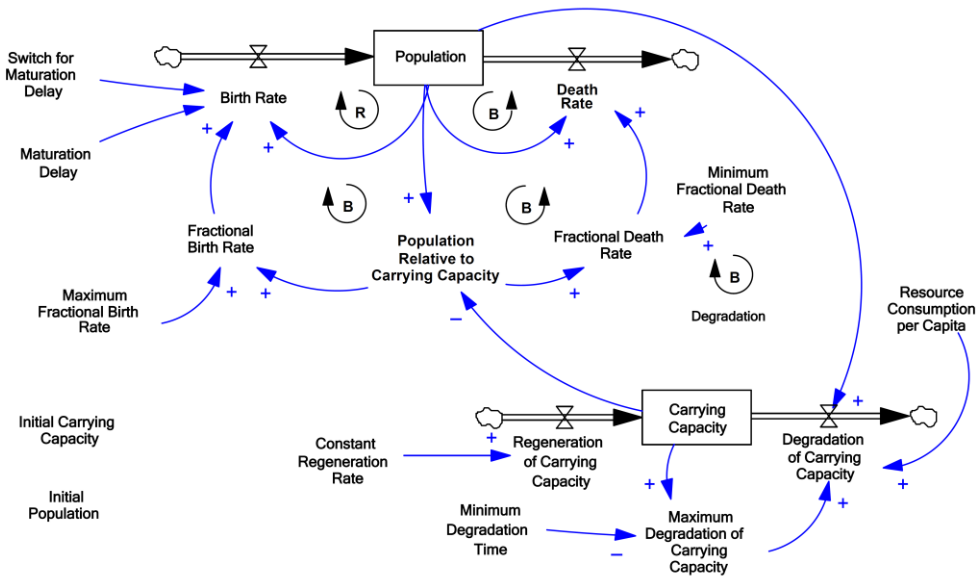


Fig. 7: Population versus carrying capacity systemic model (Sterman, 2012; 2017)

In this context, as the population and economy grow, resources per capita fall in two ways. First, there are more people for a limited quantity of resources. Second, the carrying capacity itself begins to fall as resource consumption and degradation exceed regeneration and restoration (Fig. 8).

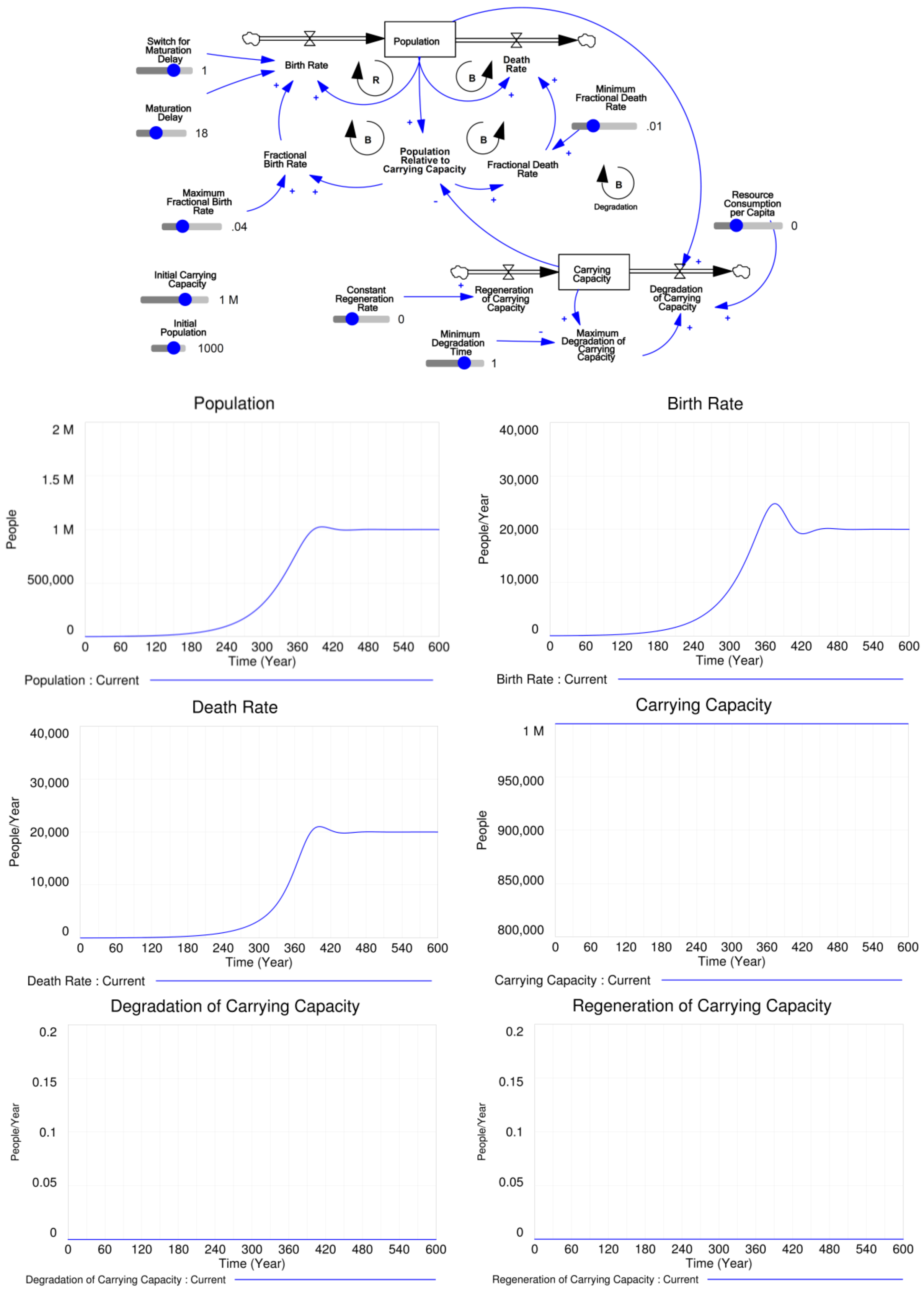
- If regeneration is rapid and regeneration capacity robust, then regeneration quickly rises to offset resource consumption, and the decline in the carrying capacity will be slight. Human population and activity will continue to grow until resources become scarce enough to halt the increase.
- If regeneration is weak and slow, then carrying capacity will fall. In this case, the high level of human activity means degradation of the carrying capacity exceeds regeneration, so the carrying capacity of the earth continues to fall. Economic output and/or human population must fall” (Benmoussa, 2020; Sterman, 2012).

In the extreme, if the population remains dependent on nonrenewable resources or generates wastes that cannot be dissipated, the carrying capacity must continue to fall as long as there is any remaining activity and the only equilibrium is zero population, which is really nonrealistic; hence, the role and impact of the technology.

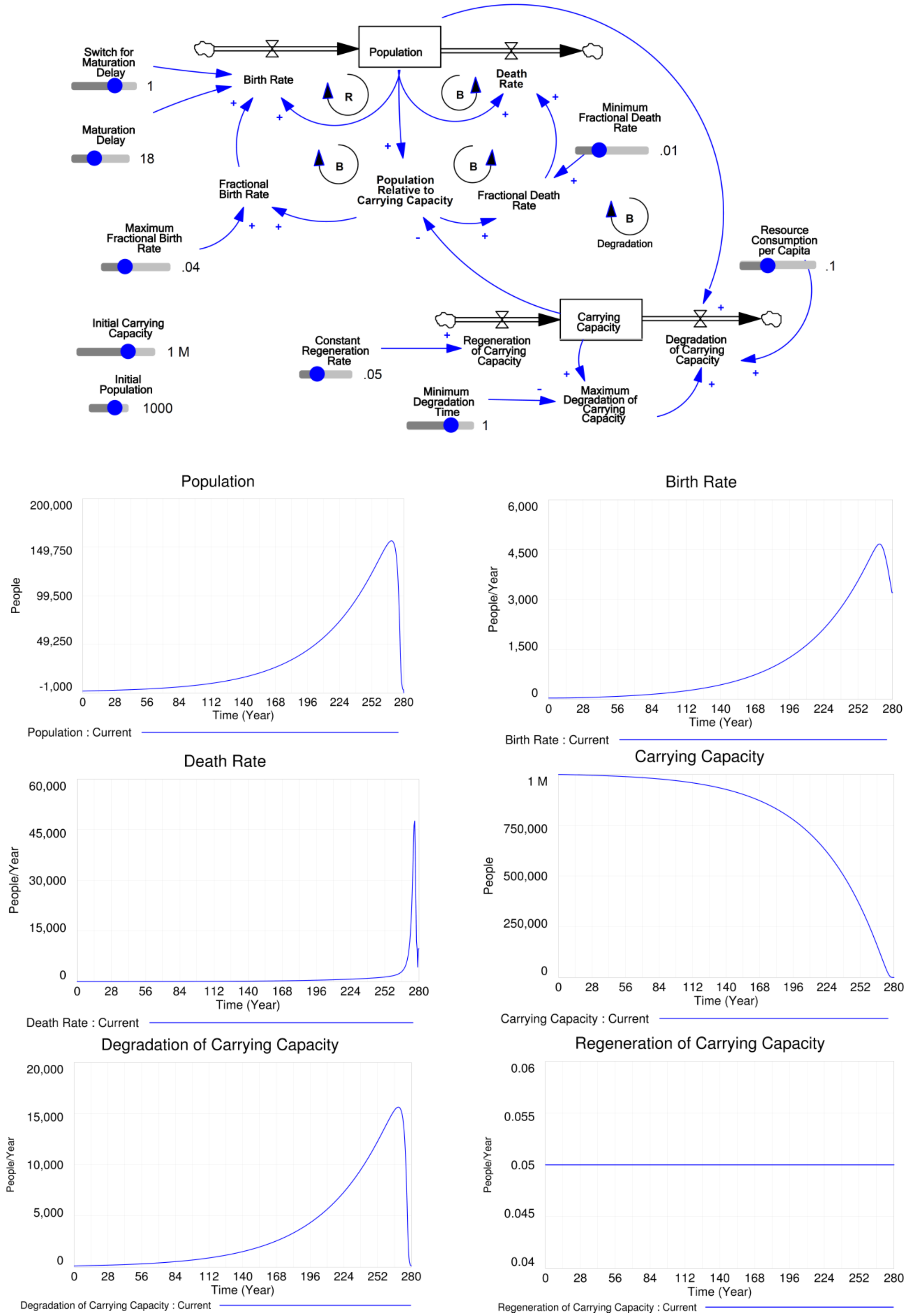
Nevertheless, incorporating the dynamics of the carrying capacity changes the system dynamics from overshoot and collapse to an S-shaped growth.

4.2. Results and discussion

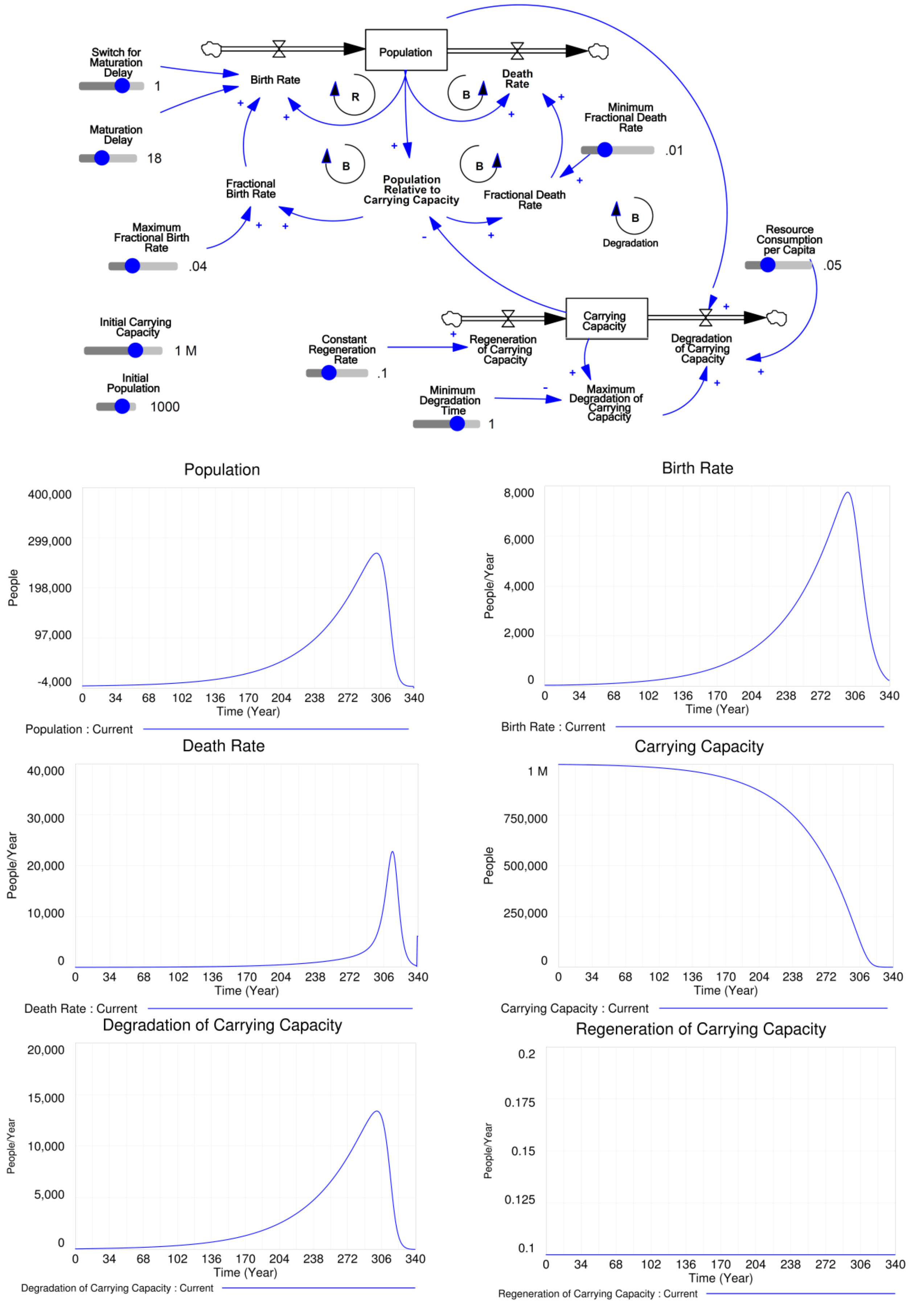
Based on the model proposed, different simulations executed on the Vensim simulator and sensitivity analysis were run as illustrated in Figs. 8a, 8b, and 8c.



(a)


Population
Birth Rate
Death Rate
Switch for Maturation Delay
1
Maturation Delay
18
R
B
Fractional Birth Rate
Population Relative to Carrying Capacity
Fractional Death Rate
Minimum Fractional Death Rate
.01
Maximum Fractional Birth Rate
.04
Degradation
Resource Consumption per Capita
.1
Initial Carrying Capacity
1 M
Initial Population
1000
Carrying Capacity
Constant Regeneration Rate
.05
Regeneration of Carrying Capacity
Degradation of Carrying Capacity
Minimum Degradation Time
1
Maximum Degradation of Carrying Capacity
Population
People
Time (Year)
Population : Current
Birth Rate
People/Year
Birth Rate : Current
Death Rate
Death Rate : Current
Carrying Capacity
Carrying Capacity : Current
Degradation of Carrying Capacity
Degradation of Carrying Capacity : Current
Regeneration of Carrying Capacity
Regeneration of Carrying Capacity : Current

(b)



(c)

Fig. 8: (a) Basic simulations; (b) Simulations with weak and slow resources regeneration (in comparison with the scenario c, on one side, and scenario a, on the other side); (c) Simulations with a rapid and robust resources regeneration (in comparison with the scenario b, on one side, and the scenario a, on the other side)

Thereby, the different scenarios developed above and the corresponding simulations indicate that the population increase at a macroscopic level cannot continue as that indefinitely and is hardly synonymous with sustainable economic growth insofar as, despite a proven rigor in terms of resources consumed per inhabitant and a breakthrough technological transformation highlighted through the variable "regeneration of carrying capacity," the latter undergoes a frank and inevitable degradation.

This mathematically highlighted observation is in perfect agreement with the qualitative analysis carried out upstream, more particularly through the proposed systemic model and the human activity profile over time, described above, perfectly matching with the "Limits to Growth" theory (Meadows et al., 1972).

Therefore, “if resources and environmental capacity are sufficient and economic growth and development are distributed equitably, then the world will move through the demographic transition and population will eventually stabilize with high life expectancy and somewhat low fertility.

Otherwise, if global economic development comes at the expense of poor people or if other problems caused by growth, such as pollution, and resource shortages ..., limit development, then the economic and social conditions that lead to low birth rates, on one side, and to demographic transition, on the other side, will not occur” (Sterman, 2017).

In this framework, population and economic growth will continue to rise, simultaneously with an acceleration of environmental degradation, reducing the earth’s carrying capacity and increasing mortality. A decline in population and economic output will undoubtedly take place within about 2 to 3 hundred years, despite a relative environmental awareness that is developing more or less timidly.

5. Conclusions and further research

Rapid population growth will entail a heavy burden on society. In a country, overpopulation and poverty often go together. It was the case depicted above for Egypt and somewhat also for Morocco.

Viewed worldwide, the rapid growth of population will inevitably result in the overconsumption of world resources and human existence should be compromised.

In this framework, based on the causal loop diagram of population, the system dynamic model proposed helps to determine the true direction to adopt, by following the hereinafter two fundamental rules as results of our modeling, also inspired and confirmed by Meadows et al. (1982; 1992; 2004).

1. If the present growth trends in world population, namely massive industrialization, pollution, food production, and resource depletion, continue unchanged, the limits to the growth of the earth will be reached sometime within the next 2 to 3 hundred years if our environmental awareness evolves positively. The dropout will happen suddenly and uncontrollably, altering our industrial capacities.
2. Nevertheless, it remains possible to “alter these growth trends and to establish a condition of ecological and economic stability that is really sustainable far in the future. The state of global equilibrium could be designed so that the basic material needs of each person are satisfied and each person has an equal opportunity to realize his individual human potential” (Meadows et al., 1982; 1992; 2004).

Consequently, if people decide to adopt the second upshot (Ayadi and Sessa, 2020; Webb, 2020; Leal et al., 2019), avoiding the Tragedy of the Commons (Hardin, 1968; Ostrom, 1990), rather than the first, the sooner they seriously and worldwide begin working to reach it, the greater will be the opportunities for authentic sustainable growth.

To conclude, the science of global modeling using a combination of techniques and methods such as system dynamics, structural equation modeling, and multi-criteria decision aid should be used to improve the model proposed in this paper, trying to find the right balance between those, alarmists, who advocate a soon uncontrolled situation and others, easygoing and maybe somewhere oblivious, who warn against any drastic form of growth limitation susceptible to plunge billions of people into permanent poverty. Finally, poorly defined and understood policies may create unanticipated side effects, and attempting to stabilize a system can destabilize it and lead to some policy resistance.

Appendix A: Models description

(01) Birth Rate = Switch for Maturation Delay*DELAY3 (Fractional Birth Rate*Population, Maturation Delay) + (1 - Switch for Maturation Delay) * Fractional Birth Rate * Population
Units: People/Year
Births are proportional to the population. When the Switch for Maturation Delay = 0, those born immediately add to the population and can reproduce, die, and consume the carrying capacity. When the switch = 1, there is a third-order maturation delay with an average delay time of the Maturation Delay before births enter the population stock.
(02) Carrying Capacity = INTEG (+Regeneration of Carrying Capacity-Degradation of Carrying Capacity, Initial Carrying Capacity)
Units: People
The carrying capacity defines the equilibrium or maximum sustainable population. It is consumed and degraded by the population and can also regenerate.
(03) Constant Regeneration Rate = 0
Units: People/Year
Exogenous constant regeneration rate, set by the user.
(04) Death Rate = Fractional Death Rate*Population
Units: People/Year
Deaths are proportional to the population.
(05) Degradation of Carrying Capacity = MIN (Maximum Degradation of Carrying Capacity, Population * Resource Consumption per Capita)
Units: People/Year

The carrying capacity of the environment is consumed or degraded in proportion to the population. The minimum function ensures that degradation falls to zero as the carrying capacity falls to zero (carrying capacity can never be negative).
(06) FINAL TIME = 600
Units: Year
The final time for the simulation.
(07) Fractional Birth Rate = Maximum Fractional Birth Rate*(1-(1/(1+exp(-7*(Population Relative to Carrying Capacity-1)))))
Units: 1/Year
The fractional birth rate is a declining function of the population relative to the carrying capacity. A logistic function is used based on time series data.
(08) Fractional Death Rate = Minimum Fractional Death Rate*(1+Population Relative to Carrying Capacity^2)
Units: 1/Year
The fractional death rate is an increasing function of the ratio of population to carrying capacity. A power function is assumed.
(09) Initial Carrying Capacity = 1e+006
Units: People
The initial carrying capacity of the environment.
(10) Initial Population = 1000
Units: People
The initial population.
(11) INITIAL TIME = 0
Units: Year
The initial time for the simulation.
(12) Maturation Delay = 20
Units: Year
The average maturation delay.
(13) Maximum Degradation of Carrying Capacity = Carrying Capacity/Minimum Degradation Time
Units: People/Year
The maximum degradation rate is determined by the carrying capacity and the minimum degradation time. This formulation captures the fact that the carrying capacity must remain nonnegative and that damage to the environment falls as there is less undamaged environment remaining.
(14) Maximum Fractional Birth Rate = 0.04
Units: 1/Year
The maximum fractional net birth rate.
(15) Minimum Degradation Time = 1
Units: Year
The minimum time constant for the degradation of the environment.
(16) Minimum Fractional Death Rate = 0.01
Units: 1/Year
The minimum fractional death rate.
(17) Net Birth Rate = Birth Rate-Death Rate
Units: People/Year
The net birth rate is births less deaths.
(18) Net Fractional Birth Rate = Fractional Birth Rate-Fractional Death Rate
Units: 1/Year
The net fractional birth rate is fractional births less fractional deaths.
(19) Population = INTEG (Birth Rate-Death Rate, Initial Population)
Units: People
The population is increased by births and decreased by deaths.
(20) Population Relative to Carrying Capacity = Population/Carrying Capacity
Units: Dimensionless
The ratio of population to carrying capacity determines the fractional birth and death rates.
(21) Regeneration of Carrying Capacity = Constant Regeneration Rate
Units: People/Year
Regeneration of the carrying capacity. Equal to a constant rate set by the user.
(22) Resource Consumption per Capita = 0
Units: People/Person/Year
Resource consumption per capita, expressed in people-equivalent units of carrying capacity consumed per person per year.
(23) SAVEPER = TIME STEP
Units: Year
The frequency with which output is stored.
(24) Switch for Maturation Delay = 0
Units: Dimensionless
1 = Maturation delay between births and entering the population. 0 = No maturation delay.
(25) TIME STEP = 0.5
Units: Year
The time step for the simulation.

Compliance with ethical standards

Conflict of interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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