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Knowledge based dynamic human population models

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ABSTRACT

Human population models have evolved from demographic models to information based models and eventually to knowledge production based models. In this study dynamic population models based on knowledge production are used to evaluate the effect of productivity functions and variable Earth potential capacity definition on population estimates. In dynamic population models, the Earth's carrying capacity is not defined as a constant, but it is defined as a function of time dependent knowledge level. The models developed require only two calibration parameters, thus they are suitable for predictive analysis. The results indicate that maximum population level estimates on Earth will be around 8–12 billion people within the next century, after which populations will be in a declining trend at different rates given the impacts of environmental degradation which is interpreted as the outcome of technologic developments. The use of lower technologic knowledge levels, which is identified as environmentally friendly technologies, will provide several centuries of high population levels which is encouraging.

1. Introduction

Humans rely on Earth's resources and engineered systems for their exploitation to support human populations. Elements of these resources include food, energy, minerals and water, availability of which are limited. Engineered systems are knowledge based resource exploitation processes that are developed to increase the carrying capacity of Earth. The use of these systems have increased the Earth's carrying capacity substantially, however mismanaged and uncontrolled exploitation of Earth's resources have always created problems for humans as well as the environment. Thus, knowledge production and its use is a double edged sword. Knowledge production is necessary to increase the Earth's carrying capacity, however mismanaged utilization of this knowledge may create adverse environmental impacts that may limit this capacity.

Dynamic process created between societal needs and demands, and engineered productivity to meet this demand, is not sustainable if humans do not address the broader impacts of the technological innovations that are adopted. It is important for us to understand how to mitigate the downward spiral that may be created and identify a possible and feasible solution to this complex problem. Probably, new perspectives are needed to determine how society can best integrate resources and engineered systems to provide for the growing demand, while maintaining quality of life for increasing human population on Earth.

Appropriate resource exploitation for sustainable and stable human population is a grand challenge. One argument is that, humans need to produce and use knowledge at an increasing rate to create a balance between resources and current population levels. The other argument is that, this is not a good proposition to solve the problem since knowledge production and its use will always be associated with environmental degradation. Our purpose in this study is to investigate if rate of increase of knowledge production and the appropriate use of this knowledge is the key element for humans to cope with and mitigate the adverse impacts of technologic applications, and maintain human population growth on Earth.

Addressing the problems mentioned above through knowledge production is not a new concept. Humans have historically relied on knowledge to increase Earth's carrying capacity. Early arguments on this topic can be found in the arguments of Marquis de Condorcet (1743–1794) and Thomas Robert Malthus' (1766–1834) (Aral, 2014a, 2014b). Our findings indicate that humans may have to challenge themselves to prolong the impending population decline to reach a balance between knowledge production rate and the environmentally safe use of this knowledge to slow down the adverse environmental impacts. This last step is not only a function of rate of increase knowledge, but it may require moral adaptations beyond knowledge

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[1] Mahmut Burak Okuducu contributed to the computational aspects of the submitted study.

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generation for the new system created to be successful. Our findings indicate that the stability of populations on Earth may not be directly linked to the increase of knowledge production rate alone.

If one puts aside the data fitting and extrapolation studies, the population modeling concepts that are proposed in the literature have evolved from demographic models, to information based models, to knowledge production based models. This evolution is healthy and also expected since humans have historically relied on information and knowledge production to overcome the limitations imposed on them for survival (Cohen, 1995; Malthus, 1798). The argument made in the knowledge based population models is that the rate of increase of world population and the rate of increase of information stored and knowledge produced by civilizations is correlated, baring catastrophic events which may produce temporary population shifts. In this modeling approach the goal is to mathematically define knowledge production based on technological advances and incorporate it into classical mathematical models of demographic growth through the use of logistic functions (Dolgonosov, 2012a, 2012b). The challenge in this approach is first in the quantification of technologic level and knowledge production, and second in the incorporation of these definitions into the logistic functions of population models in a systematic and logical manner. A good effort in this direction can be found in Dolgonosov and Naidenov (2006) and Dolgonosov (2016) in which the analytical concepts of this line of thinking are discussed in detail. As reported in these studies, the purpose is to develop algorithms that would require fever empirical (calibration) constants while linking knowledge production to population growth, and this may render the resulting models more suitable for predictive analysis of population growth. This observation is reasonable for the general analysis presented in Dolgonosov (2016). However, the limitation introduced in the selection of the productivity function as a constant and a priory definition of Earths carrying capacity as a constant, seems to be against the basic premise of the technologic development concept adopted in Dolgonosov (2016). In this study our efforts will first focus on overcoming these limitations, while adopting the basic principles of knowledge production models of Dolgonosov (2016). The second purpose of this study is to investigate if the increased knowledge production rate will provide for stable human population growth on Earth, or is there a need for the development of other imperatives beyond knowledge production that may provide this stability. This analysis is presented within the limitations of knowledge based models presented in the literature (Dolgonosov, 2012a, 2012b, 2016; Dolgonosov and Naidenov, 2006).

In this study the writers do not to claim that the knowledge production based population models developed here, and also in the literature, will accurately reflect the near or long term population trends. As indicated in Aral (2013) that would be a rather difficult proposition. We also acknowledge that there is no other alternative to computer simulations if one wants to predict the future. Given these observations, we will proceed with the use of knowledge based models to address the goals of the study and evaluate the relative change that maybe observed in human populations trends, or pave the way for the search of other imperatives in population modeling.

2. Human population models

The three principles that are used in the development of population models, in the order they were introduced to the literature are: (i) demographic models in which rate of change of population is a function of population (Foerster et al., 1960); (ii) information based models that are built on (i) in which it is assumed that populations recognize, store and process information but does not create knowledge from information and this effects population growth (Akaev and Sadovnichy, 2010, 2011; Akaev et al., 2012; Chernavsky, 2004; Kapitza, 1992, 1996; Miranda and Lima, 2010, 2011; Naidenov and Kozhevnikova, 2003; Taagepera, 2014); and, (iii) knowledge based models that are again built on (i) but in this case populations produce knowledge for their survival based on the information recognized, stored and processed (Dolgonosov, 2009, 2010a, 2010b, 2012a, 2012b, 2016; Dolgonosov and Naidenov, 2006). In their simplest form, the mathematical models of type (i) can be given as,

$$\dot{N} = \frac{N^2}{C} \tag{1}$$

where N is the world population, C is a calibration coefficient and over dot implies time derivative. As determined by Foerster et al. (1960), $C = 2 \cdot 10^{11}$ person-year constant that produces a good fit for the population trends until the current year. The general form of the mathematical models of type (ii) can be given as,

$$\dot{N} = rN^2(t-\tau_1)\left(1 - \frac{N}{K(N_c\tau_2\tau_3)}\right) \tag{2}$$

where r is the growth coefficient, t is time, and K is the logistic function which is a function of Earth's carrying capacity N_c, and several other parameters τ_i that represent the mean reproduction age, information diffusion and biosphere response lag times (Kapitza, 1992, 1996). The details of the general form of mathematical model of type (iii) is given in (Dolgonosov, 2016). Since in this study we will use a mathematical model of type (iii), it may be appropriate to summarize the mathematical definitions of this approach based on Dolgonosov's work.

Generalized knowledge based population dynamics system can be associated with the familiar minimization principle of a knowledge based function over time,

$$\int_{t_1}^{t_2} L(q,\dot{q},t)dt = \min \tag{3}$$

where $L(q,\dot{q},t)$ is a knowledge production function and $q(t)$ is the knowledge function. The minimization problem given in Eq. (3) is equivalent to the identification of a function $L[q,\dot{q}]$ which satisfies the Lagrangian,

$$\frac{d}{dt}\frac{\partial L}{\partial \dot{q}} - \frac{\partial L}{\partial q} = 0 \tag{4}$$

It can be shown that the nontrivial solutions of Eq. (4) is only associated with quadratic and higher order terms of the $L[q,\dot{q}]$ function which can be defined in terms of an infinite series,

$$L(q,\dot{q}) = a_2(q)\dot{q}^2 + a_3(q)\dot{q}^3 + O(\dot{q}^4) \tag{5}$$

where the coefficients of this series $a_2(q)$ and $a_3(q)$ are functions of q. Eq. (5) can be rewritten as,

$$L(q\dot{q}) = a(q)\dot{q}^2[1 + c(q)\dot{q}] + O(\dot{q}^4) = \frac{a(q)(\dot{q})^2}{(1 - c(q)\dot{q})} + O(\dot{q}^4) \tag{6}$$

where $a(q) \equiv a_2(q) > 0$ and $c(q) = \frac{a_3(q)}{a_2(q)} > 0$, and are identified as resource consumption and breaking knowledge productions functions respectively. Substituting Eq. (6) into Eq. (4) and omitting fourth and higher order terms the generalized knowledge dynamics equation can be obtained as follows, (Dolgonosov, 2016),

$$\ddot{q} = k(q)\dot{q}^2[1 - b(q)\dot{q}] \tag{7}$$

where,

$$k(q) = \frac{a'(q)}{2a(q)};\ b(q) = c(q) + \frac{c'(q)}{k(q)} \tag{8}$$

In Eq. (8) the superscript prime refers to the derivative of the function with respect to q, $b(q)$ is a function of resource limitation and resource consumption parameters, and $k(q)$ is given as the ratio of the rate of resource consumption to resource consumption. Since knowledge production is a function of population and productivity of humans, the rate of knowledge production can be defined as a function of a productivity function $w(q)$ and population $N(t)$ as follows,