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Explaining the origin of the Anthropocene and predicting its future

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Abstract. New interpretation of the Anthropocene is presented, the interpretation based on the rigorous analysis of the growth of human population and of economic growth in the past 2,000,000 years, which are found to have been hyperbolic. The Anthropocene appears to transcend the geological epochs of Pleistocene and Holocene. Anthropogenic impacts evolved over a long time on the canvas of hyperbolic growth of population. There were probably various stages of the Anthropocene in the past 2,000,000 years or even over a longer time. The current stage is distinctly different because now, for the first time in human existence, we are shaping our global future and even the future of our planet. This modern stage of the Anthropocene is characterised by the rapid growth of population, rapid economic growth, rapid consumption of natural resources and rapidly increasing impacts on the environment. All these features can be easily explained by characteristic properties of hyperbolic growth. Hyperbolic distributions are slow over a long time and fast over a short time. The origin of the Anthropocene can be explained as the natural consequence of hyperbolic growth of population. The mechanism of the Anthropocene can be also explained by referring to the mechanism of the growth of population. The beginning of the current stage of the Anthropocene is difficult or maybe even impossible to determine because anthropogenic impacts are likely to have been increasing monotonically. The future of the Anthropocene, which is also our future, is uncertain because it is dictated by many critical anthropogenic trends, but notably because the size of the world population is predicted to continue to increase at least until the end of the current century to a possibly unsustainable level and because the world economic growth follows now an unsustainable trajectory. Effects of the current human activities might affect global ecosystems for a long time into the future but we might not be there to see them.
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1. Introduction

Never before, in the long history of our planet, was there a single species that had such profound impacts on the environment as humans. We have a potential of converting this little speck of life in our Solar System to a hostile and uninhabitable world but we also have a potential to survive and even prosper. Our origin and our impacts on the environment can be traced to the emergence of *Homo Sapiens* around 200,000 years ago or even earlier (Weaver, Roseman & Stringer, 2008), but maybe even to between 2 and 3 million years ago, if we consider the origin of the genus *Homo*. However, our strong impacts became apparent only recently.

To understand the dynamics of our impacts it is essential to study the growth of population and the economic growth because anthropogenic impacts are the

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reflection of the growth of population and the economic growth is the reflection of anthropogenic impacts.

Our impacts are now so profound that a new geological epoch, the Anthropocene, has been proposed and is becoming widely accepted (Crutzen & Stoermer, 2000; Ehlers & Krafft, 2006; Steffen, Grinevald, Crutzen & McNeill, 2011; Zalasiewicz, Williams, Steffen & Crutzen 2010). This apparently new epoch is described extensively in my book (Nielsen, 2006), which contains a comprehensive analysis of all critical trends shaping the future of our planet. I have divided them into seven groups, (1) the rapid growth of population generally described as the population explosion; (2) the diminishing land resources (3) the diminishing water resources, (4) the destruction of the atmosphere, (5) the approaching energy crisis, (6) social decline and (7) conflicts and the increasing killing power. This book is full of facts and figures, which can be used to understand the Anthropocene.

The primary driving force of the Anthropocene is the rapid growth of population. Consequently, in order to explain its origin, it is essential to understand the mechanism of growth of human population. We have to have clear understanding of this topic. Unfortunately, there are certain strongly misleading and scientifically unsupported misconceptions in this field of study (Nielsen, 2016a). The related issue is the economic growth, which turns out to follow similar time-dependent trajectories. This field is also affected by similar misconceptions (Nielsen, 2014, 2016a). They are all based on impressions and when closely analysed they are found to be contradicted by data. We cannot afford being guided by such misconceptions. The risk is too great.

Having described in my book the panorama of all critical trends shaping the future of our planet, I have devoted the past few years on the investigation of the growth of population and of the economic growth. I have formulated a general law of growth (Nielsen, 2016b) and I have used it to explain the mechanism of growth (Nielsen, 2016c). A compilation of my publications in these fields of study is now presented in a single document (Nielsen, 2017a). My new research is now focused on the investigation of the current economic growth and of the growth of population. I have formulated a mathematical method of analysis of growth trajectories and of forecasting (Nielsen, 2017b), which I use to analyse the current growth. The aim of this work is to understand the most likely trajectories of the future growth, to understand the warning signs and to understand what needs to be done to ensure a sustainable future.

Growth of human population in the past 2,000,000 years was slow (Nielsen, 2017c). The first billion of global population was reached around AD 1800 (Biraben, 1980; Durand, 1974; McEvedy & Jones, 1978; Thomlinson, 1975; United Nations, 1973, 1999). Thus, it took many thousands of years, indeed even millions of years, for the world population to increase to one billion but after reaching the first billion, the second billion was added in just only about 130 years (United Nations, 1999). The process of many thousands of years, or even millions of years, was suddenly compressed to just over 100 years. Consumption of natural resources and the stress on the environment increased rapidly. It might be surprising that we have survived this enormous stress.

If adding one billion in just 130 years sounds too fast, the next billion was added in just 29 years, the next in 15 years, the next in 13 years, and the next in 12 years, increasing the size of global population to 6 billion (US Census Bureau, 2017). The last billion, which boosted global population to 7 billion, was added in 13 years (US Census Bureau, 2017). We call it the slowing-down growth (because the last billion was added in 13 years rather than in 12 years or even in a shorter time) but obviously the slowing down process is still too slow.

When closely analysed, data show consistently that the growth of human population and the economic growth in the past 2,000,000 years were hyperbolic (Nielsen, 2016d, 2016e, 2016f, 2016g, 2016h, 2016i, 2016j, 2017c, 2017d). Hyperbolic growth started to be diverted gradually to slower, non-hyperbolic trajectories only recently, around 1950 (for the global growth of population and for the global economic growth) but the new trajectories are still close to the original hyperbolic trajectories. For the regional growth, the diversions occurred, in some cases, even earlier. The fast growth of population in recent years is the natural outcome of hyperbolic growth. Consequently, in order to explain the origin of the Anthropocene it is essential to have clear understanding of hyperbolic growth. Indeed, the current prevailing misconceptions about the growth of population and about the economic growth are based on the incorrect understanding of hyperbolic growth.

Hyperbolic growth is slow over a long time and fast over a short time but it is still the same, monotonically increasing growth, which cannot be divided into two different components. Hyperbolic growth has to be interpreted as a whole. The same mechanism of growth has to be applied to the slow and to the fast growth.

It is incorrect to interpret the slow growth as stagnation and the fast growth as explosion, each governed by a different mechanism of growth. We can loosely describe the recent fast growth as explosion as long as we understand that it is just a perceived feature, which did not occur at any specific time and that it is a feature, which is just *the natural continuation of hyperbolic growth*. It is controlled by precisely the same mechanism as the slow growth. The Anthropocene is the natural consequence of hyperbolic growth but, as we shall see, its beginning cannot be determined.

2. Hyperbolic distributions

In order to understand hyperbolic growth, it is convenient to compare it with the more familiar exponential growth. They are both presented in Figure 1.

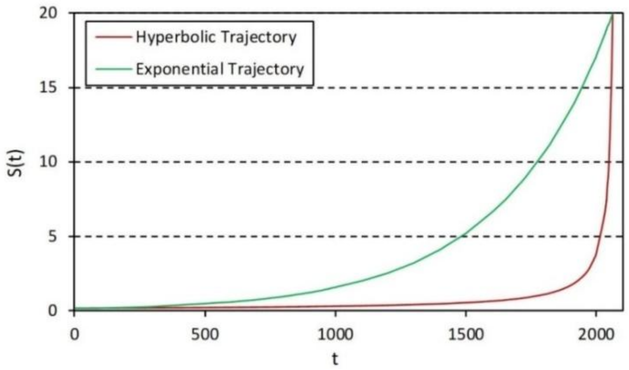

Figure 1. *Exponential and hyperbolic trajectories. Hyperbolic growth creates an illusion of an explosion at a certain time. The change of direction from the nearly horizontal to the nearly vertical growth is real but the time of the change cannot be mathematically determined. Hyperbolic growth increases monotonically.*

Exponential growth is described by the following equation:

$$S(t) = ae^{kt} , \quad (1)$$

where $S(t)$ is the size of the growing entity (in our case, the size of population or the size of the Gross Domestic Product (GDP), representing economic growth), a is the normalisation constant, k is the constant representing growth rate and t is the time.

For the distribution shown in Figure 1, $a = 1.414\times10^{-1}$ and $k = 2.400\times10^{-3}$. The size $S(t)$ is in billions and the time is in years.

Hyperbolic growth is described by the following equation:

$$S(t) = \frac{1}{a - kt} \ . \qquad (2)$$

Parameters a and k are positive constants but k does not represent the growth rate. For the distribution shown in Figure 1, $a = 7.061 \times 10^{0}$ and $k = 3.398 \times 10^{-3}$.

In the case of the exponential growth, there is no confusion. It is clear that its trajectory increases monotonically and that there is no explosion. However, hyperbolic growth might be puzzling and confusing. Such distributions create a serious problem in the demographic and economic research.

Hyperbolic growth is slow over a long time, so slow that it is approximately horizonal. Then, over a certain short time it appears to be changing its character and increases so fast that it becomes nearly vertical. It might be tempting to divide this distribution into two, or maybe even three components and assign to them distinctly different mechanisms of growth. However, such a division would be a serious mistake, the mistake which is unfortunately repeated in the demographic and economic research. Hyperbolic growth cannot be divided into different components and the best way to see it, is to display its reciprocal values:

$$\frac{1}{S(t)} = a - kt \ , \qquad (3)$$

because in this form, hyperbolic growth is represented by a decreasing straight line, as shown in Figure 2. It is precisely the same distribution as shown in Figure 1 but now plotted differently. Properties of mathematical distributions do not change when they are plotted in different ways but certain features, which are not clear in one representation might become clear in another. It is, indeed, now clear that hyperbolic distributions cannot be divided into different components. This conclusion is so obvious that it is hard to understand how it was possible to create the Unified Growth Theory, which is firmly based on the assumption of the existence of three distinctly different regimes of growth (Galor, 2005, 2011). Mistakes can be made but mistakes can be also corrected and science has many examples of corrected mistakes.

Now it is also clear that it is impossible to identify the time or the small range of time on the hyperbolic distribution, which could be claimed as a transition from a slow to a fast growth. Which point on the straight line could be claimed as the time of an unusual acceleration?

The transition occurred over the whole range of hyperbolic growth. There was no unusual acceleration at any time because such an unusual acceleration would be reflected in a change of direction of the straight-line trajectory. The straight line remains undisturbed, which means that there was no unusual acceleration at any time.

The nearly vertical growth, which is usually described as explosion, is just the natural continuation of hyperbolic growth. It is represented by precisely the same straight line as the line corresponding to the slow growth, which means that the mechanism describing the slow growth must be the same as the mechanism describing the fast growth.

It is impossible to determine the time of transition from the slow to fast growth because there was no transition at any time but a gradual transition over the whole range of hyperbolic growth. If we accept that the fast growth of population identifies the Anthropocene, then it is now clear that its beginning cannot be mathematically determined.

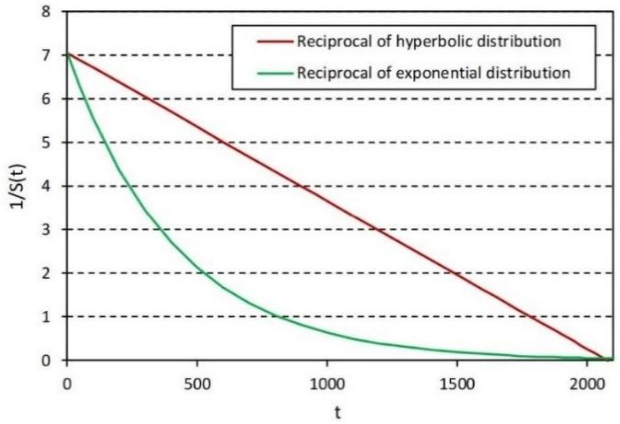

Figure 2. *Reciprocal values of hyperbolic growth show clearly that hyperbolic distribution cannot be divided into two or three different components because it makes no sense to divide a straight line into different components. The change of direction shown in Figure 1 did not occur at any specific time but over the whole range of hyperbolic growth. Reciprocal exponential distribution is also displayed. It is an exponentially decreasing distribution.*

Figure 2 shows also the reciprocal of the exponential growth, which is now represented by the exponentially decreasing distribution.

$$\frac{1}{S(t)} = \frac{1}{a} e^{-kt} . \qquad (4)$$

We can take yet another approach to dispel the illusion of stagnation followed by a sudden explosion by using semi logarithmic set of coordinates, as shown in Figure 3.

In this form, exponential growth is represented by a straight line. Hyperbolic growth is now also clearly seen as a monotonically increasing distribution. It is again obvious that there is no unusual acceleration at any time. It is obvious that it would be futile to try to identify a place for a transition from a slow to a fast growth.

The illusion of a possible sudden transition is only seen in Figure 1. Any attempt to determine a transition from a slow to a fast growth would be strongly subjective and mathematically unjustified. There is no mathematical criterium, which can be used to determine when hyperbolic growth changes from slow to fast. The change takes place monotonically over the whole range of hyperbolic distribution.

Even for the linear scales, such as used in Figure 1, the illusion of an unusual acceleration at a certain time depends on the compression of linear scales. Let us, for instance, magnify the part of the plot, which appears to be showing the unusual acceleration described commonly as explosion. Such magnification is shown in Figure 4, again using linear scales. Now we can see that the change from slow to fast growth occurs gradually without any unusual change of direction. Any attempt to determine the time of change or even the small range of time would be strongly subjective and mathematically unjustified.

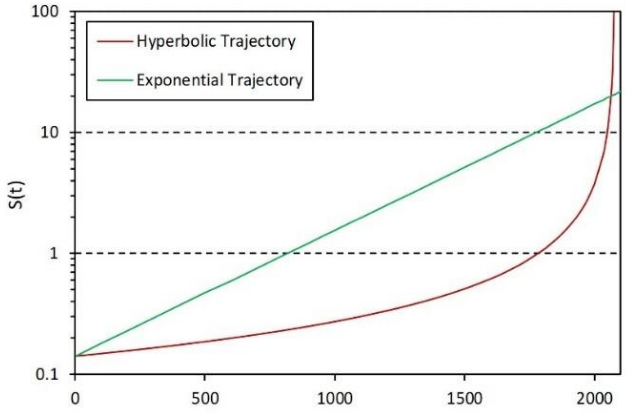

Figure 3. *Semilogarithmic representation of exponential and hyperbolic distributions. Hyperbolic distribution increases monotonically and the change of direction occurs along the whole range of growth.*

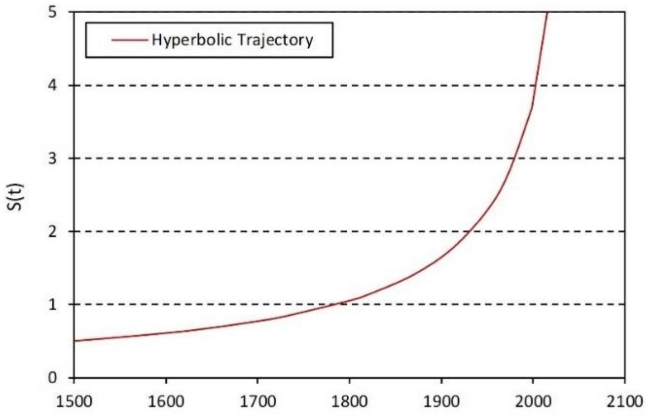

Figure 4. *Magnified part of the linear display used in Figure 1, focusing now on the section where there was an illusion of a sudden change from slow to fast growth at a certain time. Even by using linear scales, the illusion of sudden explosion is replaced by the natural continuation of the same growth.*

3. Growth rate

In order to understand hyperbolic distributions, we have to understand also their growth rate. Again, we shall compare the growth rates of hyperbolic and exponential distributions.

Exponential growth is a solution of the following differential equation:

$$\frac{1}{S(t)}\frac{dS(t)}{dt} = k\,. \tag{5}$$

The left-hand side of this equation is, by definition, the growth rate. For the exponential growth, the growth rate is constant. It does not matter how large is the size of the growing entity, the growth rate remains all the time the same, which means that the growth rate per element of the growing entity (in our case it would be per person or per dollar) decreases exponentially with the increasing size of the growing entity.

Hyperbolic growth is a solution of the following differential equation:

$$\frac{1}{S(t)}\frac{dS(t)}{dt} = kS(t)\,. \tag{6}$$

It is just a small modification of the differential equation describing exponential growth but with profound consequences. For the hyperbolic distributions, the growth rate is not constant but directly proportional to the size of the growing entity. Now, the growth rate per element (per person or per dollar) of the growing entity is constant. It is a special kind of a self-propelling growth. Each element contributes equally to the growth process. The larger is the size of the growing entity, the larger is the combined force of growth and the faster is the growth. This is an important characteristic property, which identifies hyperbolic growth. This characteristic property can be used to explain the mechanism of the hyperbolic growth of human population. Likewise, the equivalent property that the growth rate is directly proportional to the size of the growing entity can be used to explain the mechanism of the hyperbolic economic growth.

We can now use parameters describing exponential and hyperbolic distributions shown in Figures 1-3 to calculate their corresponding growth rates. They are shown in Figure 5.

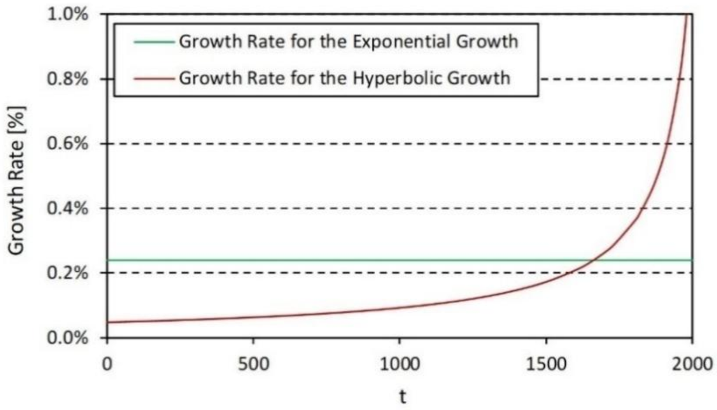

Figure 5. *Growth rates for the exponential and hyperbolic distributions displayed in Figure 1. Growth rate for the exponential distribution is constant, while the growth rate for the hyperbolic distribution increases monotonically without any signs of unusual acceleration at any time or over any small range of time. It is mathematically impossible to determine the time of transition from the slow to fast growth.*

We can see that while for the exponential distribution the growth rate is constant, for the hyperbolic distribution it increases monotonically with time. Indeed, for the hyperbolic growth its growth rate increases also hyperbolically. It is because the growth rate per element of the growing entity is constant that the combined growth rate increases relentlessly with time. It is mathematically impossible to determine the time of change from slow to fast growth. The change takes place monotonically over the whole range of hyperbolic growth.

We can also display the growth rate as the function of the size of the growing entity. Such a display is shown in Figure 6.

It is because the growth rate per element is constant that the combined growth rate for the hyperbolic growth is directly proportional to the size of the growing entity, i.e. to $S(t)$ which in our case is the size of population or the size of the GDP. This display illustrates again that hyperbolic growth cannot be divided into two or three different components and a transition from slow to fast growth cannot be associated with any specific time or with any small range of time. The transition was gradual over the entire range of hyperbolic growth.

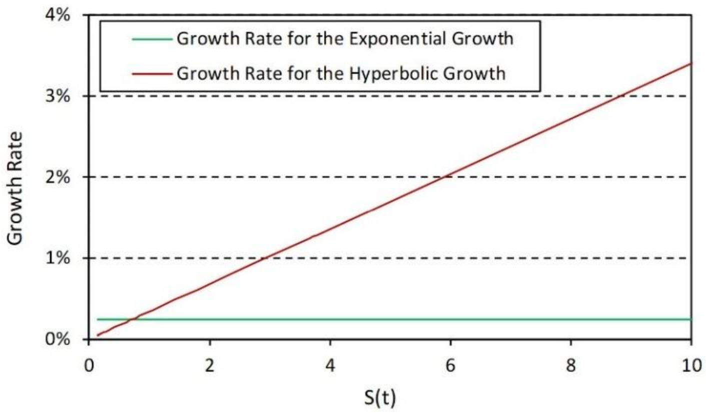

Figure 6. *Growth rates plotted as functions of the size of the growing entity. The growth rate for the exponential growth is constant. For the hyperbolic growth, it is directly proportional to the size of the growing entity. This plot demonstrates again that hyperbolic growth cannot be divided into two or three different regimens of growth, as erroneously assumed in the Unified Growth Theory (Galor, 2005, 2011). It also shows that there was no unusual acceleration in the growth rate at any time and thus that the transition from the slow to fast growth cannot be assigned to any time or to any small range of time. The transition was occurring over the whole range of hyperbolic distribution.*

4. The doubling time

It is also useful to have clear understanding of the concept of the doubling time. It is important to understand that the concept of characterising growth in terms of the doubling time *applies only to the exponential growth. The doubling time should never be used to describe any other type of growth* because it is only for the exponential growth that the doubling time represents the characteristic feature of growth. Using the doubling time to characterise or describe non-exponential distributions is as useful as describing the cuttlefish as, for instance, a green animal. For any non-exponential distribution, the doubling time changes as we follow the trajectory of growth.

The doubling time for the exponential growth is given by the following formula:

$$T_2 = \frac{\ln 2}{k}. \tag{7}$$

This formula can be easily derived using eqn (1). If we express k in percent, then this formula can be rewritten as

$$T_2 = \frac{69.3}{k'} \approx \frac{70}{k'}, \tag{8}$$

where k' is now expressed in per cent. This is the so-called "rule of 70" which is routinely but erroneously applied to any type of growth but it *should be applied only to the exponential growth.* Applying it to any other type of growth is not only meaningless but also misleading because by applying it we assume that any other type of growth is exponential while it is not. If trying to characterise non-exponential growth by the doubling time is already bad enough, using the formula (7) or (8) is even worse. It simply makes no sense.

For the hyperbolic growth, the doubling time is not constant. It depends on time. Using eqn (2) we can show that the doubling time for the hyperbolic growth is given by

$$T_2 = \frac{1}{2}\left(\frac{a}{k} - t\right). \quad (9)$$

It is a mathematically correct formula but it has a limited application and consequently it should be used with care, if at all. For instance, for the hyperbolic distribution shown in Figure 1, at $t = 1000$, the doubling time is 540 years. It means that staring from precisely that time, hyperbolic growth would double in 540 years. However, if we started from $t = 1100$, then the doubling time would be 490 years. Only 100 years difference and the doubling time is already significantly different. If we started from $t = 2000$, the doubling time would be 40 years. Such calculations might be interesting, for whatever reason, but they could be of little use.

The doubling time is routinely used to project growth but if applied to any other growth than exponential, the projection is both meaningless and misleading. To project growth for any other type of growth, a simple but more sophisticated method of analysis should be used (Nielsen, 2017b). Prediction of growth cannot be based on the growth rate at a certain fixed time, as for the exponential growth, but on the investigation of the growth rate over a sufficiently long period of time

5. Hyperbolic growth during the AD time

Growth of population and of the GDP during the AD time are shown in Figures 7 and 8. Data (Maddison, 2010) are compared with hyperbolic distributions. More extensive analysis is presented in separate publications (Nielsen, 2016d, 2016e, 2016g, 2017c).

Parameters describing hyperbolic growth of population are: $a = 8.724 \times 10^0$ and $k = 4.267 \times 10^{-3}$. Parameters describing the growth of the GDP are: $a = 1.716 \times 10^{-2}$ and $k = 8.671 \times 10^{-6}$.

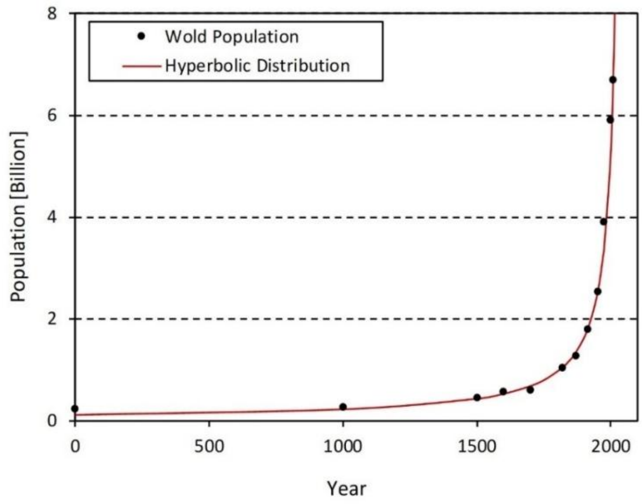

Figure 7. *Data describing growth of the world population (Maddison, 2010) are compared with hyperbolic distribution. Growth of population was not exponential, as incorrectly imagined by Malthus (1798) and as often claimed, but hyperbolic.*

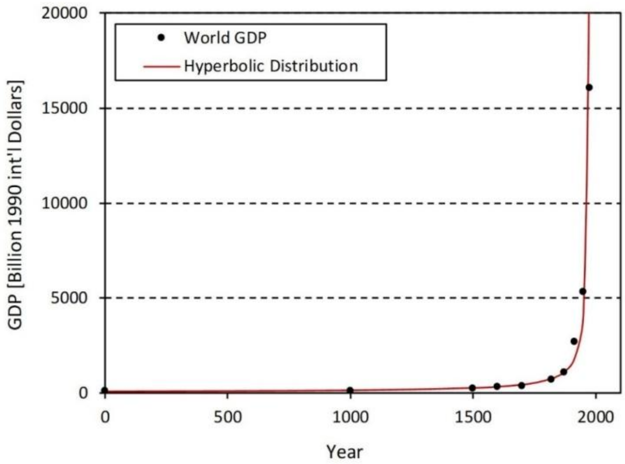

Figure 8. *Data describing growth of the world Gross Domestic Product (Maddison, 2010) are compared with hyperbolic distribution. Economic growth was hyperbolic.*

Hyperbolic growth of the world population was demonstrated as early as in 1960 (von Foerster, Mora & Amiot,1960). This important discovery is generally ignored. I have devoted the past few years of my life to understand the growth of population and economic growth, the two crucial processes propelling the Anthropocene and shaping our future.

1. I have introduced a simple method of analysis of hyperbolic distributions (Nielsen, 2014, 2017e).
2. I have demonstrated that hyperbolic description of the growth of population applies not only to the growth of the world population, as studied by von Foerster, Mora & Amiot (1960), but also to the growth of regional populations (Nielsen, 2016g).
3. I have demonstrated that hyperbolic description of growth applies also to the economic growth, global and regional (Nielsen, 2016d).
4. I have extended the analysis of the growth of the world population to the BC time (over the past 12,000 years) and demonstrated that hyperbolic growth applies not only to the AD time, as pointed out by von Foerster, Mora & Amiot (1960), but also to the BC time (Nielsen, 2016e).
5. I have extended the analysis of the growth of population and of the economic growth over a longer time (i.e. over the past 2,000,000 years) and confirmed the earlier observation of Deevey (1960) that the growth of population was in three major stages, but I have demonstrated that these stages were hyperbolic (Nielsen, 2017c).
6. I have explained the puzzling features of income per capita (GDP/cap) distributions by showing that they represent nothing more than mathematical properties of dividing two hyperbolic distributions (Nielsen, 2017d).
7. I have examined Galor's mysteries of growth (Galor, 2005, 2011) and explained them by showing that they are based on the incorrect understanding of hyperbolic distributions (Nielsen, 2016h, 2016j, 2017e) and on his habitual distorted representations of data.
8. I have demonstrated that the Unified Growth Theory describing economic growth and the Demographic Transition Theory describing the growth of population are based on the incorrect understanding of hyperbolic distributions and are contradicted by data (Nielsen, 2014, 2016d, 2016f, 2016g, 2016l, 2016m).
9. I have analysed the effects of the Malthusian positive checks and demonstrated that they have a dichotomous impact on the growth of

population (Nielsen, 2016k) and thus, I have confirmed the earlier observation of Malthus (1798) about his positive checks and supported them by data, observation which is also unfortunately generally ignored.

10. I have demonstrated that, with only one exception demonstrated in a weak and short-lasting impact, demographic catastrophes did not shape the growth of population (Nielsen, 2016e, 2017f).
11. I have repeatedly demonstrated that Industrial Revolution had no impact on shaping growth trajectories, even in Western Europe and even in the United Kingdom (Nielsen, 2014, 2016d, 2016f, 2016g, 2016i, 2016m, 2016n, 2017e).
12. I have formulated a general law of growth (Nielsen, 2016b) and used it to explain the mechanism of hyperbolic growth of human population and of economic growth (Nielsen, 2016c).

If hyperbolic distributions are confusing, they are significantly simpler than that the distributions describing income per capita represented by the GDP/cap. This issue was discussed in separate publications (Nielsen, 2016h, 2017d). Income per capita distributions (empirical and theoretical) for the world economic growth during the AD era are shown in Figure 9. They were obtained by dividing the relevant distributions shown in Figures 7 and 8.

Distributions describing income per capita are nothing more than just linearly-modulated hyperbolic distributions. They also increase monotonically and there is no transition from a slow to fast growth at any time or over any small range of time, even though the linear display creates a strong illusion of such a transition.

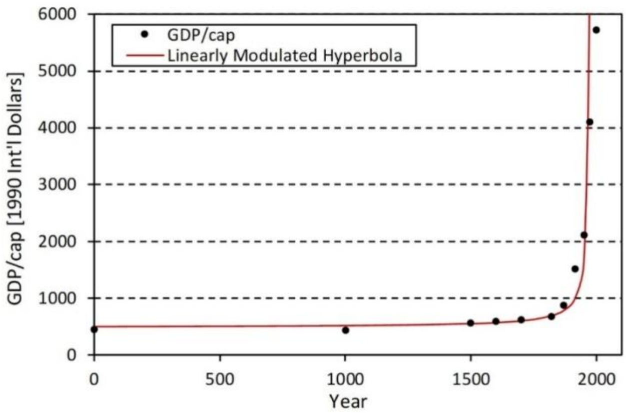

Figure 9. *Income per capita distributions (GDP/cap) obtained by dividing distributions shown in Figures 7 and 8. The puzzling features of growth (the approximately constant value over a long time followed by a rapid increase over a short time) represent nothing more than just the mathematical properties of dividing two hyperbolic trajectories (Nielsen, 2017d). The best fit to the data is simply a linearly-modulated hyperbolic distribution. Distributions shown in Figures 7 and 8 increase monotonically and consequently the distributions describing the growth of income per capita also increase monotonically, which can be easily confirmed by the analysis of the growth rate and of the gradient of the GDP/cap growth (Nielsen, 2017d). There was no stagnation and no explosion at any time.*

There is nothing profoundly mysterious about the income per capita distributions. Their puzzling properties are nothing more than just mathematical properties of dividing two hyperbolic distributions. It is as simple as that.

The shape of the ratio of two hyperbolic distributions depends on the relative position of their singularities. If the singularity for the population distribution were earlier than the singularity for the GDP distribution, then the GDP/cap distribution would not be increasing to infinity but it would be decreasing to zero. For the distributions displayed in Figures 7 and 8, singularities are: $t_s = 1979$ for the GDP and $t_s = 2045$ for the growth of population. The distribution representing the GDP/cap ratio escapes rapidly to infinity in 1979. If the singularities were reversed, the distribution representing the GDP/cap would decrease rapidly to zero in 1979.

The mechanism of growth of the GDP/cap ratio can be easily explained. It is the same mechanism which describes the growth of the GDP and the growth of population, and the mechanism is exceptionally simple (Nielsen, 2016c; see section 7), which is hardly surprising because mathematical formula describing hyperbolic growth is also simple.

The fast-increasing income per capita is undeniably real but it did not start at any specific time and neither was it caused by any mysterious force. It is the natural consequence of the action of precisely the same forces that prompt hyperbolic growth of population and hyperbolic economic growth, forces that change monotonically and produce monotonically increasing trajectories. There is no need for introducing or for imagining any other additional force acting at any specific time to cause this rapid increase. There is no triggering mechanism, no ignition and no sudden explosion.

The rapid increase is the feature, which represents the natural consequence of the monotonically increasing hyperbolic distributions, and the characteristic shape of the GDP/cap distribution is nothing more than just the mathematical property of dividing two, monotonically increasing, hyperbolic distributions. We can take any two hyperbolic distributions described by the eqn (2) and divide them. As long as the singularity of the numerator is earlier than the singularity of the denominator, we shall get the characteristic features of the GDP/cap distribution. The mystery of the GDP/cap distributions is solved and the solution is simple.

6. Hyperbolic growth in the past 2,000,000 years

Growth of population in the past 2,000,000 years is shown in Figure 10 (Nielsen, 2017c). Similar trajectory is for the economic growth.

This study confirms the earlier observation (Deevey, 1960) that the growth of population over such a long time was in three stages. However, while Deevey imagined that each state was leading to an equilibrium, my analysis shows that each stage was hyperbolic. This can be seen explicitly in Figure 11. The first stage does not look like hyperbolic in this graph but it is hyperbolic (see the explanation in my publication, Nielsen, 2017c).

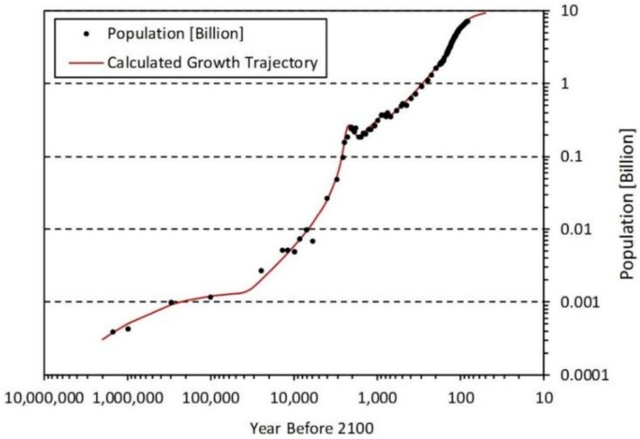

Figure 10. *Growth of human population in the past 2,000,000 years.*

It is remarkable that hyperbolic growth was so stable over such a long time. There were only two major transitions in the past 2,000,000 years. The first transition was between 46,000 BC and 27,000 BC and it was a transition from a slow to a faster hyperbolic growth. The second transition was between 425 BC and

AD 510. It was a transition from a fast to a significantly slower hyperbolic trajectory.

There was also a minor disturbance during the AD time, which occurred between AD 1195 and 1470. This transition represents one and only example of impacts of demographic catastrophes (Nielsen, 2016e, 2017c, 2017f). A convergence of five major demographic catastrophes were needed to cause a minor and short-lasting disturbance in the growth of population, the disturbance, which was soon compensated by a faster growth, reflecting the stimulating effects of Malthusian positive checks (Malthus, 1798; Nielsen, 2016k). This transition changed the earlier hyperbolic trajectory to a slightly faster trajectory. The overall characteristics of the two trajectories are so similar that they can be replaced by a single trajectory fitting the data reasonably well (Nielsen, 2016e).

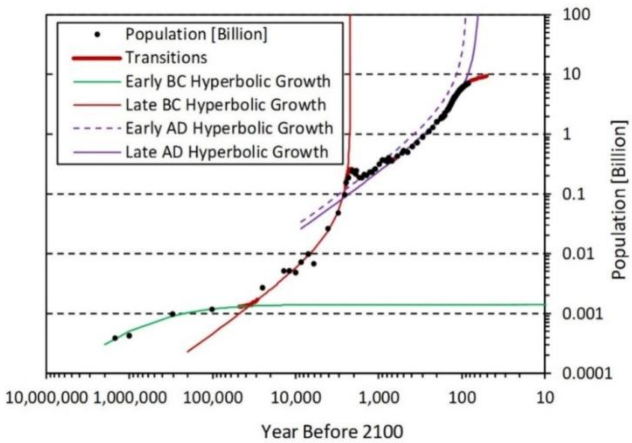

Figure 11. *Three major stages of growth of the world population in the past 2,000,000 years: (1) between 2,000,000 BC and 27,000 BC, (2) between 27,000 BC and AD 510 and (3) between AD 510 BC and the present time. Each stage ends with a transition to a new stage. The last stage experienced a minor distortion between around AD 1195 and 1470. This distortion caused a small shift in the hyperbolic growth. With just these three interruptions, growth of population in the past 2,000,000 years was hyperbolic leading inevitably to the Anthropocene. This proposed new epoch is the natural consequence of hyperbolic growth but its onset cannot be mathematically determined.*

Currently, from around 1950, there is now a new transition to a yet unknown trajectory. This transition appears to be shaped by the increasing application of the Malthusian preventative checks but is counteracted by the stimulating effects of the Malthusian positive checks in poor countries (Nielsen, 2016k).

Growth of population and economic growth in the past 2,000,000 was consistently hyperbolic. It was interrupted a few times but it soon resumed its hyperbolic growth. Relentlessly and persistently, it was increasing the size of the world population.

The characteristic feature of hyperbolic growth is that it contains singularity, a fixed time when the size of the growing entity increases to infinity. Close to the singularity, the size increases so fast that it can become uncontrollable. Nothing can increase to infinity and consequently, such a fast growth has to be terminated either catastrophically or by gradually diverting it to a different trajectory.

The late BC hyperbolic growth was so fast that, if continued, would have increased to infinity in 104 BC. Fortunately, it started to be diverted to a new trajectory in around 425 BC. The singularity was bypassed by a large margin of around 321 years. At the time of the commencement of this major transition, the size of the wold population was small, only around 140 million.

The point of singularity for the later AD hyperbolic growth is in 2037 but it was bypassed by 87 years when the growth started to be diverted to a new trajectory around 1950. However, this diversion started with a minor boosting, which brought the growth of population closer to the point of singularity. Furthermore, the size of the world population in 1950 was around 2.5 billion, much larger than the size of population in 425 BC. We are now in a far worse position with controlling the growth of population and with diverting it to a new and safe trajectory.

Analysis of the growth of population suggests a gradual evolution of the Anthropocene over the past 2,000,000 years, or even over a longer time, on the canvass of the hyperbolic growth. The same pattern applies also to the economic growth (Nielsen, 2017c), which reflects our impacts on the environment. The currently experienced exceptionally strong impacts are the consequences of the natural continuation of the monotonically increasing hyperbolic growth in much the same way as the apparent population explosion is just the natural continuation of hyperbolic growth.

7. The mechanism of hyperbolic growth

If you expect complicated explanations of the mechanism of growth of human population and of the economic growth, you will not find them here. Hyperbolic growth is described by an exceptionally simple mathematical equation [see eqn (2)], and it could be, therefore, expected that the interpretation of the underlying mechanism should be also simple. In science, simple solutions and explanations are tried first, or at least they should be tried first. More complicated explanations are suggested only if simple solutions do not produce satisfactory results.

Every growth can be, and usually is, described using growth rate. This is the quantity, which characterises growth. The larger is the growth rate, the faster is the growth.

Every growth is prompted by some kind of a force. We can assume, and indeed it appears to be obvious, that the driving force of growth is reflected or encoded in the growth rate. The stronger is the force of growth the larger is the growth rate and the faster is the growth. Furthermore, the force of growth determines and describes the mechanism of growth.

We might imagine a variety of correlations between the force of growth and the growth rate but the simplest correlation is represented by a force directly proportional to the growth rate:

$$F(t) = \kappa R(t), \tag{10}$$

where κ can be described as the resistance to growth and $R(t)$ is the growth rate,

$$R(t) = \frac{1}{S(t)} \frac{dS(t)}{dt}. \tag{11}$$

In science, simple descriptions are tried first because natural phenomena can be usually described using simple principles. Complicated descriptions are avoided. They are introduced only if simple descriptions are inapplicable and they often suggest that we are on a wrong track and that we should look for an alternative simple description.

Equation (10) represents the general law of growth (Nielsen, 2016b). This law can be used to formulate a variety of models of growth. Possibilities are virtually unlimited.

The advantage of using this law of growth is that it links growth trajectories with the force of growth, which represents the mechanism of growth. Calculated trajectories might be represented by complicated mathematical formulae but by using this law of growth they can be usually based on simple assumptions about the force of growth or at least by assumptions that can be easily interpreted and easily related to the real life.

Thus, for instance, logistic model of growth is based on the assumption that the force of growth decreases linearly with the size of the growing entity. However, we might imagine a variety of other shapes for the trajectories describing the driving force. This force might, for instance, remain approximately constant over a certain range of sizes and then it might start to decrease gradually, faster or slower. Another possibility is that again the force of growth might not decrease linearly but approximately exponentially with the size of growing entity. Here, again, even if we assume a fixed starting point for the force of growth and a fixed, asymptotically approachable limit to growth, we can have various representations of the force of growth, each producing a different model of growth but all of them belonging to the same family of models, which resemble the logistic model of growth but are represented by different mathematical formulae. Our task then is not to explain the complicated mathematical descriptions of growth trajectories but the significantly simpler and maybe even intuitively understood descriptions of the driving force.

Often, even if we use simple representations of the driving force, mathematical description could be so complicated that the relevant differential equations have to be solved numerically. However, the starting assumptions can be usually simple. Again, in order to explain the mechanism of growth we do not have to explain the mathematically complicated descriptions of growth trajectories but the simple descriptions of the driving force. This approach simplifies considerably the study of the mechanism of growth.

The fundamental force of growth of human population is obviously the *biologically-controlled force of procreation* expressed as the difference between *the biologically-controlled sex drive,* which is ultimately related to birth rate and *the biologically-controlled process of aging and dying*, reflected in death rate. It would be unrealistic to expect that we should provide microscopic mathematical description of these biologically controlled forces. Such a task would be impossible and even if attempted it would quickly lead to some extremely complicated and incomprehensible formulations. Maybe by being so complicated they would be sufficiently impressive to be readily publishable in peer-reviewed journals but we would learn nothing useful from them. However, the net effects of these biologically controlled forces can be mathematically modelled in a simple, comprehensive and convincing way.

We can imagine many other forces controlling or prompting the growth of human population but by following the fundamental principle of parsimony in scientific investigations, we should consider first only the force of procreation and add to it other forces, if necessary. This force is essential and it cannot be replaced by other force of forces. We can add other forces to this force but we cannot replace it by any other force.

The simplest way to model the net effect of the biologically prompted force of procreation is to assume that on average it is *constant per person*:

$$\frac{F(t)}{S(t)} = c \,, \tag{12}$$

where c is a positive constant.

If we now use this definition of the driving force and insert it into the general law of growth given by the eqn (10), we shall get the eqn (6), which describes hyperbolic growth. In this equation, $k = c / \kappa$.

Thus, by assuming the simplest possible force of growth, we have now *derived* the hyperbolic growth equation. No other force is needed. *Hyperbolic growth of population represents the simplest possible mechanism of growth*, the unconstrained and spontaneous growth prompted by the, on average, constant per capita biologically controlled force of procreation.

If other forces make a significant contribution to the growth process, the growth is no longer hyperbolic. These rare exceptions occurred only three times in the past. The first time during the transition from a slow to a much faster hyperbolic trajectory between 46,000 BC and 27,000 BC, the second time between 425 BC and AD 510 and the third time between AD 1195 and 1470. Currently, starting from around 1950, the growth of population is also no longer hyperbolic, even though it is still following closely the original hyperbolic trajectory. We are in the process of a new transition to a yet unknown growth. It remains to be seen whether this will be short or long transition.

Analysis of data does not allow for the determination of parameters c and κ but only of their ratio, c/κ. However, for convenience, in the interpretation of the empirically determined parameter k, we might assume that the parameter c remains the same all the time and that only the resistance to growth is changing. Hyperbolic growth between around 2,000,000 BC and 46,000 BC was characterised by an exceptionally large resistance to growth. During the transition between 46,000 BC and 27,000 BC, resistance to growth was undergoing a major adjustment to a new value. From around 27,000 BC, the resistance to growth was exceptionally low and the hyperbolic growth was fast (as measured by the parameter k) until around 425 BC, which marked the onset of a new adjustment in the resistance to growth. The new adjustment continued until around AD 510. From around that year, growth of human population settled along a new but slower hyperbolic trajectory (again as measured by the parameter k). During the minor disturbance between AD 1195 and 1470 the resistance to growth increased but the new hyperbolic trajectory from around AD 1470 was characterised by a slightly lower resistance to growth than the trajectory before AD 1195, reflecting the regenerating effects of the Malthusian positive checks (Malthus, 1798; Nielsen, 2016k). The two hyperbolic trajectories, before AD 1195 and after AD 1470 are virtually identical. They are only slightly shifted in time and they can be replaced by a single trajectory (Nielsen, 2016e). However, the two slightly shifted hyperbolic trajectories give a better description of data.

Equation describing hyperbolic growth [see eqn (2)] is exceptionally simple and it is therefore hardly surprising that the mechanism of hyperbolic growth is also simple. Explanation of the mechanism of the historical economic growth is also simple.

It is well known that wealth generates wealth. Again, any attempt to describe mathematically the microscopic interactions of all market forces would lead to incomprehensible, unconvincing and unserviceable mathematical formulations but we can model mathematically their net effect. We might consider a variety of factors contributing to the generation of wealth but the simplest possible mechanism is based on the assumption that, on average, the generated wealth is directly proportional to the already existing wealth. Under this simplest assumption, the force of the unconstrained economic growth is given by

$$F(t) = \rho W(t), \tag{13}$$

where ρ is a constant and $W(t)$ is the existing wealth.

If we insert this force into the eqn (10), we shall get

$$\rho W(t) = \kappa R(t), \tag{14}$$

where

$$R(t) = \frac{1}{W(t)} \frac{dW(t)}{dt}, \tag{15}$$

which now leads us to the equation

$$\frac{1}{W(t)}\frac{dW(t)}{dt} = kW(t), \tag{16}$$

where $k = \rho / \kappa$.

This is again the equation describing hyperbolic growth. Thus, by assuming the simplest possible mechanism of economic growth we have *derived* the differential equation describing hyperbolic growth. Again, hyperbolic growth describes the simplest process of growth. More complicated descriptions of the force of growth are unnecessary.

8. The future of the Anthropocene

The future of the Anthropocene is dictated by the current convergence of critical trends shaping our future (Nielsen, 2006) but most notably by the growth of population and by the economic growth. We shall now examine what we can expect in these two areas. Calculations are based on my method of analysis of growth rates (Nielsen, 2017b).

8.1. Growth of population

The top part of Figure 12 shows the growth rate for the growth of the world population calculated directly from the population data (US Census Bureau, 2017). From around 1963, the growth rate was systematically decreasing. We can use these data to project growth.

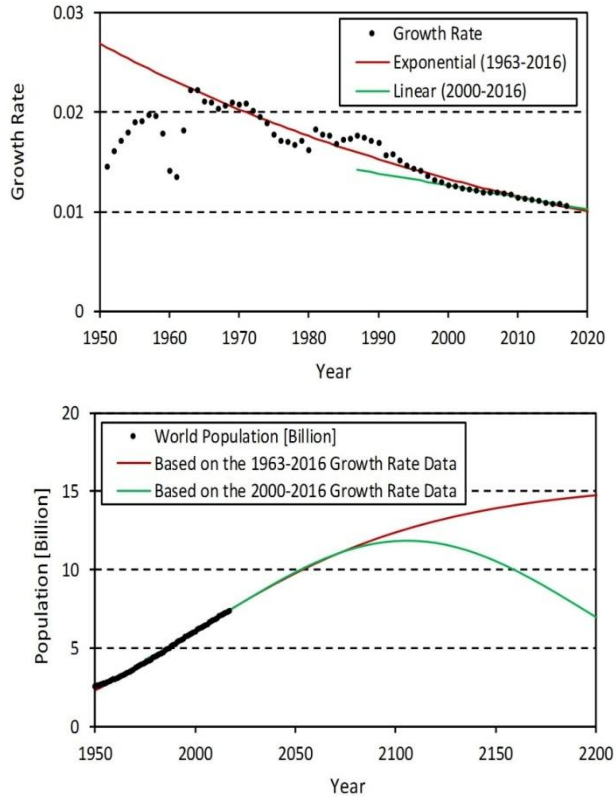

Figure 12. *Forecasting the growth of the world population. Two representations (exponential and linear) of the growth rate, calculated using the US Census Bureau (2017) data, are used to generate growth trajectories for the growth of the world population (Nielsen, 2017b, 2017e). These calculations are in good agreement with projections of the United Nation (2015). However, the UN publication gives no information about the growth of the population in the 22nd century. It is important to notice that while the growth rate continues to decrease, the growth of the world population continues to increase and is not yet levelling off. It is projected to increase at least till the end of the current century.*

We seem to have two obvious options for the mathematical description of the growth rate: (1) to use the wide range of growth rate data between 1963 and 2016, which can be well described by the exponential function or (2) to assume that from around 2000 growth rate is now settling along a linearly decreasing trajectory. The projection of growth of the world population based on fitting exponential distribution to the growth rate could be regarded as more reliable because it is based on a wide range of data but it is still possible that the growth rate will now follow a linearly decreasing trajectory.

Results of calculations are shown in the lower part of Figure 12. If the growth rate is represented by the exponential function,

$$\frac{1}{S}\frac{dS}{dt} = ae^{bt} , \tag{17}$$

then the solution of the eqn (17) is (Nielsen, 2017b):

$$S = C\exp\left(\frac{a}{b}e^{bt}\right). \tag{18}$$

For the decreasing exponential function representing the growth rate (see the top section of Figure 12), the parameter b is negative and the exponential function in the eqn (17) decreases asymptotically to zero. Consequently, S increases asymptotically to the normalization constant C. The eqn (18) could be described as a pseudo-logistic trajectory. For the world population, parameters of this trajectory are: $a = 2.179\times10^{10}$ and $b = -1.406\times10^{-2}$, and its asymptotic value is 15.6 billion. The projected population in 2200 is 14.7 billion and increasing.

If we assume that the growth rate decreases linearly with time, i.e. if

$$\frac{1}{S}\frac{dS}{dt} = a + bt , \tag{19}$$

then the solution of this equation is (Nielsen, 2017b):

$$S(t) = C\exp\left[at + 0.5bt^2\right]. \tag{20}$$

Its parameters are: $a = 2.520\times10^{-1}$ and $b = -1.197\times10^{-4}$. It reaches a maximum of 11.8 billion in 2105.

Calculations shown in Figure 12 are in good agreement with projections by the United Nations (2015). According to this source "The world population is projected to increase by more than one billion people within the next 15 years, reaching 8.5 billion in 2030, and to increase further to 9.7 billion in 2050 and 11.2 billion by 2100" (United Nations, 2015, p. 2). My prognosis is 8.4 billion in 2030, 9.8 billion in 2050 and 11.8 billion in 2100 for the trajectory leading to the localized maximum. If the growth of the world population is going to follow the trajectory leading to the asymptotic maximum, then it will also reach 8.4 billion in 2030 and 9.8 billion in 2050 but only a slightly larger size of 12.4 billion in 2100. The difference between predicted values in 2100 is so small that we shall not know until well into the next century whether we are likely to reach a localized maximum of around 12 billion or to have the population continually increasing to the asymptotic size of around 16 billion, if such a large size can be supported by the accessible resources.

Summary of all these predictions is presented in Table 1. The UN projection gives no information about the expected size of population in the 22nd century. For the 21st century, the agreement between these two independent predictions is remarkably good.

Table 1. *Predicted growth of the world population*

Source	2030	2050	2100	S_{max}	S_a
UN	8.5	9.7	11.2	NI	NI
CA	8.4	9.8	11.8	11.9	NA
CA	8.4	9.8	12.4	NA	15.6

Note: UN – United Nations, (2015); CA – current analysis (Nielsen, 2017b); NI – no information; NA – not applicable; S_{max} – maximum value; S_a – asymptotic value.

The future of the Anthropocene is uncertain. Using the most optimistic prediction, the maximum size of the world population will be around 12 billion by the end of the current century or at the beginning of the next century, i.e. around twice as high as around 2000. Shall we be able to support such a large number of people? If not, we might expect a serious crisis.

However, there is also a possibility that the world population will not reach a maximum but will continue to increase to its asymptotic value of around 16 billion. By the end of the next century it might be close to 15 billion, i.e. about twice as large as the current (in 2017) world population. Shall we be able to support such a continuing growth?

The best option, if we had an option, would be to try to slow down the growth of population even more than now experienced, but we can hardly expect that such a global undertaking will be ever attempted, or even if undertaken that it would be ever successful. It is hard to control the growth of a large size of the increasing population, and an excellent example is China. They made a determined effort to control the growth of their population and they managed to reduce their growth rate to around 0.5% from a maximum of 1.6% in 1988 (World Bank, 2017). The growth rate remained constant at around 0.5% for the past 10 years, but recently it started showing signs of a gradual increase. If the growth rate is going to remain constant, the growth of population in China will be exponential and it will never level off. If the growth of population in China is going to continue at the approximately 0.5%, its size will increase to around 2.2 billion in 2100 and to 3.6 billion in 2200. Compared with the size of the population in 2000, it will be about 65% higher in 2100 and 170% higher in 2200. By around 2140, the population in China will be approximately twice as high as in 2000.

If we wanted to control the growth of the world population, we would have to undertake a massive and consolidated effort. There are no signs that we shall ever do it. The evidence-based best option would be to improve the living conditions in poor countries because Malthusian positive checks stimulate growth (Malthus, 1798; Nielsen, 2016k), but there are no indications that this possible solution will be ever attempted. Furthermore, improving their standard of living can be only achieved by improving their economic status, which would have to be now at the cost of the economic sacrifice of richer countries, because the current global economic growth follows already an unsustainable trajectory (Nielsen, 2015).

It is also important to notice that while the growth rate is decreasing the size of the world population is increasing. It is not yet levelling off. The size of the population will start to decrease if its growth rates is going to becomes negative. It will start to level off only if its growth rate will be approaching asymptotically the zero value. If the growth rate is going to decrease asymptotically to a positive constant value, the growth of the world population will be exponential.

8.2. Economic growth

Growth rate describing the growth of the world Gross Domestic Product (GDP) is shown in Figure 13. Empirical values were calculated using the World Bank data for the GDP (World Bank, 2015).

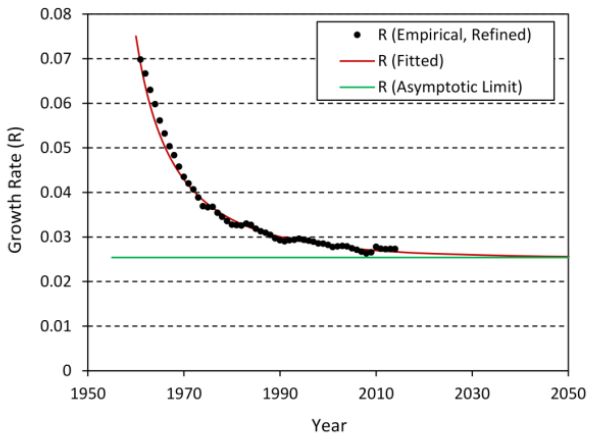

Figure 13. *Empirical growth rate [R (Empirical, Refined)] of the world GDP, calculated using the World Bank data (World Bank, 2015), is compared with the distribution described by the eqn (21). The growth rate approaches asymptotically a constant value. Constant growth rate generates exponential growth.*

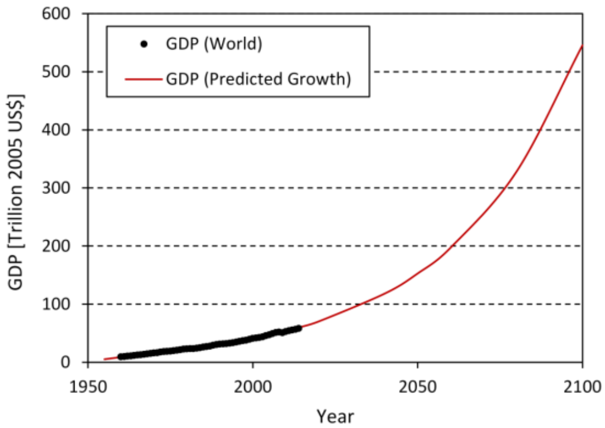

Figure 14. *Data for the world Gross Domestic Product (GDP, World Bank, 2015), expressed in trillions of the 2005 US dollars, are compared with the distribution calculated using the eqn (22). The world economic growth is now approximately exponential and consequently, over a sufficiently long time, unsustainable.*

The best fit to the growth rate data is given by the following distribution (Nielsen, 2015):

$$R \equiv \frac{1}{S}\frac{dS}{dt} = (a - be^{-rt})^{-1}. \tag{21}$$

Parameters describing empirical growth rate are: $a = 3.940 \times 10^{1}$, $b = 3.787 \times 10^{42}$ and $r = 4.836 \times 10^{-2}$. The asymptotic limit of the growth rate is 2.538×10^{-2} or approximately 2.5%. The growth rate in 2014 was 2.7%, i.e. close to its asymptotic value. Constant growth rate describes exponential growth, which after a sufficiently long time is unsustainable. Even now, the growth of world GDP is approximately exponential.

Solution of the eqn (21) is given by the following distribution (Nielsen, 2015):

$$S(t) = C\exp\left[\frac{t}{a} + \frac{1}{ra}\ln(a - be^{-rt})\right]. \tag{22}$$

Its asymptotic form is represented by the exponential function,

$$S(t \to \infty) \to C \exp\left(\frac{t}{a}\right). \tag{23}$$

The distribution given by the eqn (22) is compared with the GDP data (World Bank, 2015) in Figure 14.

Expressed in constant 2005 US dollars, the world GDP in 2014 was about 40% higher than in 2000. If the growth continues along the predicted trajectory, the size of the GDP in 2100 will be around 12 times higher than in 2000. Economic output of one year in 2000 will have to be generated in one month. In 2200, economic output will have to be around 170 times higher than in 2000. In one month we shall have to produce about 14 time more than we were producing in one year in the year 2000. Shall we be able to support such a dramatic increase in the economic growth? Even if we had a sufficient supply of natural resources, shall we be able to tolerate such continuing increase in the annual economic stress? Shall we be able to cope with such continuing increase of the annual economic output?

It seems to be clear that, over a sufficiently long time, exponential economic growth is unsustainable and that it will have to be changed. It is unlikely that global economic growth will be ever regulated and consequently any diversion from the exponential growth is going to happen most likely spontaneously, but spontaneous diversion is unpredictable. It might occur without any dramatic consequences but it could be also catastrophic.

A way out would be to start to decrease the growth rate along a suitably faster trajectory (if it could be done by some international agreement or by default). Such a gradual but consistently faster decrease of the growth rate could lead to a maximum in the size of the GDP or to its logistic limit (Nielsen, 2015). However, the general tendency is to increase the growth rate or at least to keep it constant. Economic status of a country is judged to be sound if its economic growth rate is high. It is therefore unlikely that the growth rate describing global economic growth will be decreasing faster than indicated by data, unless by default, which again indicates that the future of the Anthropocene is uncertain. This stage might have a dramatic termination sooner than we expect, the termination, which could take us by surprise in much the same way as the rapid growth of population.

Maybe, with a sufficient foresight and coordinated effort we could have controlled the growth of population when its size was still small. Maybe we could have been also able to control economic growth. Malthus (1798) was wrong in claiming that the growth of population increases geometrically (exponentially). Population was never increasing exponentially but hyperbolically. However, Malthus was right when he was warning against the excessive growth of population. His warning was about 200 years ago. We had enough time to try to control the growth of population. However, his warning has been ignored in much the same way as the repeated warnings of scientists are now also consistently ignored. The Anthropocene does not have a promising future.

9. Searching for the beginning of the Anthropocene

The Anthropocene is proposed to be a geological epoch characterised by strong human impacts on the environment. However, the analysis of the growth of human population suggests that it is difficult to determine the beginning of this epoch. Data suggest that its beginning should be perhaps traced to around 2,000,000 years ago or even earlier, to the more distant dawn of the existence of hominines.

Initially, Nature might have had the upper hand but gradually hominines were taking control of their destiny. They survived and they were making progress in their exploitation of planet's resources and in using them to their advantage. Gradually, their impact on the environment was increasing and it even became destructive but it was never as strong and as destructive as it is now.

The Anthropocene seems to transcend the Pleistocene and the Holocene epochs. Our presence, the evolution of our skills and the evolution of our impacts on the environment can be found in archaeological records. The Anthropocene is the integral part of the history of the growth of human population, which with the exception of just two or three interruptions (Nielsen, 2016e, 2017c), was hyperbolic in the past 2,000,000 years. As observed by Waters, *et al.,* (2016, p. aad2622-2) the "increase in the consumption of natural resources is closely linked with the growth of the human population."

The origin of the Anthropocene, including our current strong impacts on the environment, can be explained as being the natural consequence of the *hyperbolic* growth of human population. If we want to understand the latest fast increase in the growth of population and in the intensity of anthropogenic impacts we should look for explanation in the hyperbolic growth. Exponential growth does not produce such fast-increasing effects over a short time; hyperbolic growth does, even though it remains monotonic. The growth of population was hyperbolic. It was never exponential (Nielsen, 2016e, 2017c; von Foerster, Mora & Amiot, 1960).

The mechanism of the Anthropocene can be also explained by linking it with the mechanism of the hyperbolic growth of human population. Gradually, our impacts on the environment were increasing and eventually they became so strong and so visible that we perceive them as representing a new geological epoch, which we call the Anthropocene, but this epoch, if it is going to be recognised as a new geological epoch, started to evolve long time ago.

There were probably several stages of the Anthropocene in the past 2,000,000 years, culminating with our current stage. The precise time of the beginning of the current stage is hard, maybe even impossible, to determine. If we are looking for a suddenly-appearing marker or for a marker with an abrupt change in its intensity, a marker that we could use to determine the beginning of the modern stage of the Anthropocene, we shall definitely not find it in the growth of population or in the economic growth because there was no sustained boosting of their trajectories.

However, there is one distinctive difference between our current impacts and impacts in the past, the difference which might be used to distinguish the current stage of the Anthropocene from all other earlier stages. This difference is in the intensity of anthropogenic impacts. For the first time in human history our impacts are so strong that we are now *shaping our global future* and even the future of our planet. For the first time in human existence there is now also a large number of people living on our planet, larger than ever before. This large number of people is not a result of some new force boosting the growth trajectory but of the same force as before, the force responsible for the monotonically increasing, hyperbolic growth of population. Hyperbolic growth of population explains the fast-increasing size of the population in recent years and the fast-increasing anthropogenic impacts.

The current large size of global population and their strong impacts are the natural consequence of the *monotonically* increasing hyperbolic growth. Hyperbolic growth does not explode suddenly. It is not characterised by any sudden takeoff, sudden sprint, sudden great escape or great acceleration. All these features are the illusions of hyperbolic growth and it would be good for us to learn it and to accept it because only then we can make progress with the interpretations of our current anthropogenic impacts on the environment and with the interpretation of the beginning of the Anthropocene.

I cannot stress it too strongly that hyperbolic or hyperbolic-like distributions are exceptionally deceptive and even the most prominent researchers fall into their trap. Anthropogenic trends have to be analysed carefully and methodically to avoid making an easy mistake of seeing a sudden increase when the observed increase could be just the natural continuation of the monotonically increasing hyperbolic distribution or of a hyperbolic-like distribution. It is easy to fall into the trap of hyperbolic illusions. Many mistakes were made in the past with the interpretation of hyperbolic distributions and great care should be taken to avoid repeating such mistakes now or in the future.

The term "hyperbolic-like distribution" needs to be explained. From around AD 1470 (after the minor disturbance, which occurred between AD 1195 and 1470) the growth of human population and the economic growth were continuing to increase monotonically along hyperbolic trajectories. Any other anthropogenic signature is likely to have been increasing in much the same way, or at least increasing monotonically. Furthermore, any perceived sharp increase is likely to be just a hyperbolic illusion because the growth of population was hyperbolic and even now it is still continuing close to the historical hyperbolic trajectory (Nielsen, 2016e). It is only by a close and careful analysis of data that we can detect a slow and ongoing diversion to a new trajectory from around 1950. However, the new trajectory is still so close to the historical hyperbolic trajectory that it continues to resemble hyperbolic growth. It is a hyperbolic-like distribution because it retains the essential features of hyperbolic distribution. It does not increase to infinity at a fixed time but it increases rapidly within a small interval of time.

However, there are many other examples of hyperbolic-like distributions. Their common characteristic features are their slow growth over a long time and fast growth over a short time. They might appear to be non-monotonic but they are monotonic. A transition from a slow to a fast growth cannot be mathematically determined. It occurs monotonically along the entire range of these distributions. Hyperbolic or hyperbolic-like distributions create an illusion of a sudden increase but it is just an illusion.

When studying anthropogenic signatures, we should be on guard against such illusions. The growth of human population was hyperbolic. It is still hyperbolic-like and any anthropogenic signature is likely to be characterised by the same properties as the distributions describing the growth of human population or economic growth. Maybe some of these signatures will follow non-monotonically increasing trends but any perceived sudden acceleration in their trajectories would have to be positively identified before claiming it as a marker of a transition to the new stage of the Anthropocene. The corresponding trajectories would also have to illustrate our global impacts on the environment.

Recently, Chiaia-Hernández, *et al.,* (2017) published results of an excellent and interesting study of contamination history in two lakes in Central Europe in the past 100 years and suggested that their results could contribute to the determination of the starting point of the Anthropocene. Their data are local and many more of such high-quality data would be required to establish global correlations. However, visual examination of their diagrams (presented in *their* Figures 3 and 5) suggests that their time-dependent distributions are probably hyperbolic or at least that they increase monotonically. Plotting them by using linear scales of reference could be self-misleading. These distributions should be closely examined but they appear to have been increasing without a sudden acceleration. I do not dispute their determined maxima but I only question the apparent sudden increase in their distributions.

The "Great Acceleration" in the growth of population claimed by Waters *et al.* (2016) *definitely never happened.* It is interesting that the claimed "Great Acceleration" in the growth of population around 1950 is in fact the beginning of a *slow* diversion to a *slower* trajectory (Nielsen, 2016e, 2017c).

The claim of the "Great Acceleration" is similar to the claim of the "Great Divergence" in the economic growth (Galor, 2005, 2011), which upon closer examination was found to be contradicted by data (Nielsen, 2016j). *The "Great Divergence" never happened* and it looks that the Great Acceleration also never happened. It certainly did not happened in the growth of population or in the economic growth.

Steffen, *et al.,* (2015) published the most interesting collection of diagrams illustrating rapid increase in various anthropogenic signatures. These diagrams appear to be correct but I would question some of their sources. I also have a problem with accepting their claim of the Great Accelerations.

Various trajectories representing anthropogenic activities were increasing fast because population was also increasing fast but population was increasing fast because it was following the *monotonically* increasing hyperbolic trajectory, which was recently diverted *slowly* to a hyperbolic-like trajectory (Nielsen, 2016e). In order to understand all these fast-increasing trajectories and in order to interpret them properly we have to go back to the growth of population and understand its dynamics. All is going to become clear and less mysterious if we realise that the growth of population was not exponential but hyperbolic. We have to learn more about hyperbolic growth, we have to accept it and only then we can make progress with our understanding of the current anthropogenic impacts on the environment.

To prove the presence of the "Great Acceleration" we would have to compere the growth *before* and *after* the time of the perceived or claimed acceleration. We would have to demonstrate a clear *discontinuity* in the growth trajectory. A great acceleration would be indicated by a great discontinuity, which should be easy to demonstrate. No such clearly outlined great discontinuity is presented in the published diagrams (Steffen, *et. al.,* 2015).

What we could perhaps see as an acceleration in some rare cases is likely to be nothing more than the natural continuation of hyperbolic growth in much the same way as the perceived population explosion is also just the natural continuation of hyperbolic growth. Great accelerations would have to be proven. No such proof is presented by Steffen, *et. al.,* (2015) and no such proof is offered by Waters *et al.*, (2016).

Will Steffen informed me that the term "Great Acceleration" is not supposed to be interpreted in the mathematical sense but in a general sense, whatever it means. However, the "Great Acceleration" is supposed to have happened around or even precisely in 1950 (Waters *et al.,* 2016), so it is understood in the mathematical sense.

Acceleration implies an event, which starts to occur at a certain time. It implies a change. A change has to occur at a certain time; otherwise there is no change. The beginning of a small acceleration could be unnoticed and ignored but a great acceleration is hard to miss and it definitely should be seen as starting at a certain time.

If there is no "Great Acceleration" in the mathematical sense, then there is no Great Acceleration. If the "Great Acceleration" cannot be convincingly demonstrated, then it cannot be accepted. Imagination plays an important role in scientific research but science is not based on imaginations. It is based on data, which we can use to check our imaginations, our claims, theories and expectations. Science is based on a convincing and verifiable evidence.

The term "Great Acceleration" was coined in 2006 by a group of interdisciplinary scholars (Hibbard, *et. al.,* 2006; Steffen, 2017). It is a vague and misleading term, which should have never been introduced and definitely it should not be used.

Great Accelerations were claimed by Waters *et al.* (2016), not in a general sense but it the mathematical sense. Their numerous diagrams strongly suggest that the beginning of the Anthropocene can be determined by data but such a conclusion appears to be incorrect. Data would have to be properly analysed to see whether there was a Great Acceleration in 1950 or in some other time.

We might wish strongly to have a clear signature for the beginning of the Anthropocene but such a signature would be probably difficult, maybe even impossible, to find because the growth of population was increasing monotonically and anthropogenic signatures are likely to have been increasing also monotonically. We should be prepared that the beginning of the modern stage of the Anthropocene will probably never be positively and convincingly determined.

The desire to locate the beginning of the Anthropocene is so strong that even the imaginary Great Acceleration is used for this purpose. "Although there has been much debate around the proposed starting date for the Anthropocene, the beginning of the Great Acceleration has been a leading candidate (Zalasiewicz *et al.,* 2012)" (Steffen, *et. al.,* 2015, p. 83). Here again, the Great Acceleration is not interpreted in a general sense but in the mathematical sense because we want to use its beginning to determine the beginning of the Anthropocene. We are not referring here to the generally increasing intensity of anthropogenic impacts but to impacts that started to occur at a certain time. We would have to prove that they started to occur at a certain time before we could use their beginning to determine the beginning of the Anthropocene.

The beginning of the Great Acceleration cannot be used for determining the beginning of the Anthropocene because there is no definite proof that there was a Great Acceleration in the mathematical sense. The Great Acceleration in a general sense cannot be used to determine the beginning of the Anthropocene because the Great Acceleration in a general sense has no clearly defined beginning.

Some data describing anthropogenic impacts (Steffen, *et al*., 2004; Steffen, *et. al.,* 2015) extend to 1750. Some start from a later year, probably because there are no earlier data or because they illustrate activities that emerged only in recent years. For instance, the number of McDonald restaurants increased rapidly from 1950. We obviously cannot use this signature to determine the beginning of the Anthropocene but we could include it in a combined analysis of new trends.

Out of 24 diagrams presented by Steffen *et al.* (2004) only one ("Coastal Zone: Biochemistry") shows great acceleration just before 1950. Should we use this trend to determine the beginning of the Anthropocene? Probably not because this trend does not represent data but "*model-calculated* partitions of the human-induced nitrogen perturbation fluxes" (Steffen, *et al.* 2004, p. 133; emphasis added).

In the scientific research it is important to go with the flow, to follow the lead in data and to be always on guard not to see in data what we want to see. We might use data to *define* the beginning of the Anthropocene but it is doubtful that we shall positively *determine* its beginning. Our definition of the beginning of the Anthropocene, if clearly stated and supported by data, might or might not be accepted by the scientific community. To determine the beginning of the Anthropocene we would have to work much harder and we would have to produce convincing evidence in data.

The development and proliferation of nuclear weapons might be used to *define* the beginning of the modern stage of the Anthropocene because now, for the first time in human existence we have the power to cause *global* destruction. Certain new trends, such as production of motor vehicles, airplanes and of the synthetic fixation of nitrogen by using the Haber-Bosch process, could be perhaps also used to *define* the beginning of the Anthropocene. Maybe we could also use them to *determine* the beginning of the Anthropocene but we would have to present a sufficient number of examples of such trends to demonstrate a *clear shift* in the anthropogenic impacts. These trends would have to be minutely and carefully analysed.

Industrial Revolution could be also used to *define* the beginning of the modern stage of the Anthropocene. However, it cannot be used to *determine* its beginning because it had no impact on changing growth trajectories describing the growth of population and economic growth (Nielsen, 2014, 2016d, 2016f, 2016g, 2016n) but it probably *sustained* their hyperbolic growth. Maybe without the Industrial Revolution the growth of population and economic growth would have started to deviate to slower trajectories, but it is only a speculation, which would be hard or even impossible to proof.

Production of the reactive nitrogen could be also used to *define* the beginning of the modern stage of the Anthropocene but it cannot be used to determine its beginning because it did not cause a substantial and sustained boosting in the growth of population or in the economic growth. There was only minor and temporary boosting in the growth of population (Nielsen, 2016c), which coincides with the onset of the surge in the production of the reactive nitrogen but it was probably not caused by this production. The production of the reactive nitrogen probably also helped in sustaining the growth of population but it did not boost substantially this growth.

Stratigraphic records would be desirable but it is probably still too early to demonstrate a clear transition in stratigraphic deposits. There appears to be no stratigraphic need to use the concept of the Anthropocene as a new geological epoch. There is, however, a need to find stratigraphic evidence to support this concept.

Waters *et al.* (2016) use HYDE data base (Goldewijk, Beusen & Janssen, 2016) for the growth of population but these "data" are unreliable. I have noticed a serious discrepancy between their "data" and the data coming from reputable sources. I have asked Klein Goldewijk for explanation. He has kindly responded to my query and here is his answer: "Sometimes, it seemed to me that numbers could not have been that low, it would result in very high growth rates indeed to reach the numbers reported in later times. So I've adjusted the numbers were (sic) I felt it was appropriate. I admit that for sure most estimates are highly uncertain!" (Goldewijk, 2016). His honest answer is appreciated but if we produce "data" based on our personal likes and dislikes or on our personal prejudice we can hardly claim them as data.

These high growth rates, which worried Goldewijk so much and which looked to him unacceptable, were there *because the growth was hyperbolic*. For the hyperbolic growth, the growth rate increases hyperbolically with time or linearly with the size of the growing entity (cf. eqns (5) and (6) and see Figures 5 and 6). Goldewijk did not like the well-documented data so he converted hyperbolic growth to the exponential. So now we know that the growth was not hyperbolic but exponential as shown clearly by the fabricated "data" (Goldewijk, Beusen & Janssen, 2016). We might know it but it is not science. Data play fundamental role in scientific research and every scientist would prefer to have reliable data published in reliable sources by reputable and unbiased scientists.

Deliberate fabrication or interference with data is like an assignation of science. This is the worse we can do to the scientific research. It is worse than using data and failing to interpret them correctly. People will rely on such fabricated "data", they will use them and they will come to wrong conclusions. One incorrect conclusion will stimulate another and soon a whole pseudo-scientific field is created. We can see it in the demographic and economic research, which are based on misinterpretations of hyperbolic distributions, and now we can see it also in the research about the anthropogenic impacts, which appears to be based not only on the misinterpretations of data but also on the fabricated data. It is like cancer, spreading through peer-reviewed journals and killing science. Relying on such data is like leaning on a broken reed.

Tailored data might look attractive but they have no scientific value. Tailored data are unacceptable, even if they are perfect, because they are tailored. The HYDE data base (Goldewijk, Beusen & Janssen, 2016) is unreliable and anyone who uses it takes a risk of being led to incorrect conclusions.

Estimates of the size of human population in the past are not perfect but they are acceptable if based on unbiased research of reputable scholars. It is, however, remarkable that these imperfect estimates are so consistent that they show clearly hyperbolic growth of human population, not just over a short time, as first observed by von Foerster, Mora & Amiot (1960), but over the past 12,000 years (Nielsen, 2016e) and even over the past 2,000, 000 years; not only for the growth of global population but also for regional populations (Nielsen, 2016g); not only for the growth of population but also for the economic growth (Nielsen, 2016d). All these distributions show consistently hyperbolic growth. It is also remarkable because it would be unreasonable to suggest a collective conspiracy of various scholars working in different geographic locations and at different time to prove hyperbolic growth of population or the hyperbolic economic growth.

If you are looking for a good and reliable database for the growth of human population in the past 2,000,000, you will find it in my publication (Nielsen, 2017c). The tabulated values listed in this publication are based on a rigorous analysis of the reliable estimates of the size of population. These values represent the best fit to the data (see Figure 10). If you can trust this fit, you can trust the tabulated values. Reliable data from 1950 are listed in the International Data Base (US Census Bureau, 2017). In the same publication (Nielsen, 2017c), you will also find tabulated values describing economic growth in the past 2,000,000 years. They are based on my analysis of income per capita (Nielsen, 2017d). From 1950, data are listed by Maddison (2010) and in the Maddison Project Database (GGDC, 2013).

Waters *et al.* (2016, p. aad2622-2) mention also that "human impacts contributed to the extinction of Pleistocene megafauna." This concept was supported by Barnosky (2008) by using fabricated "data" of Hern (1999). It is interesting that, on close examination, even these fabricated data do not support the concept of human-induced extinction of megafauna (Nielsen, 2013a).

I have asked Warren Hern for the explanation of his "data" and this is what he wrote: "I did not intend in any way to offer my table of the number of doublings as 'data' or a prediction. All of the numbers – and I don't think there are any exceptions – are imprecise to wildly wrong and based on estimates ranging from considered evaluation of available data (?) to total speculation" (Hern, 2013).

Hern learned about exponential growth directly from Bartlett (Hern, 2013) who delivered around 1600 lectures on this topic and who also published a book discussing properties of exponential distributions (Bartlett, 2004). Bartlett was an excellent scholar. Unfortunately, Hern was so fascinated by what he learned that he created a table of totally fictitious numbers, which were supposed to describe the growth of human population from 3,000,000 BP (before present). His table is made of sections of exponential growth. The whole set of numbers is so obviously wrong that it is not difficult to see it and yet he published them in a peer-reviewed journal (Hern, 1999). Barnosky likes the concept of the extinction of megafauna by humans. He used the fictitious numbers of Hern for the alleged but totally fictitious growth of population (I call them *Phasmapithecus*) and published his results in a peer-reviewed journal (Barnosky, 2008). Now, this dubious and questionable claim (Nielsen, 2013a, 2013b, 2013c) is repeated without any reservation by Waters *et al.* (2016) and published also in a prestigious, peer-reviewed journal. These examples illustrate how one misinformation can spread easily around and derail scientific research.

The intensified human impacts on the environment are real and I discuss them extensively in my book (Nielsen, 2006), but there is no convincing justification for claiming a sudden acceleration in the intensity of these impacts. They appear to have been developing monotonically over a long time, maybe even over the past 2,000,000 years but only recently we started seeing them so clearly that they look as if they appeared suddenly. There is no compelling reason for assuming that they increased suddenly. On the contrary, there is a clear and compelling evidence that they did not appear suddenly, because anthropogenic impacts reflect the growth of population while the economic growth reflects the anthropogenic impacts, and both, the growth of population and economic growth, were following monotonically increasing hyperbolic distributions. The current trajectories describing the growth of population and economic growth still follow closely the historical hyperbolic trajectories.

It is obvious that the intensities of human activities increased in recent years because the growth of human population was hyperbolic, but it would have yet to be proven that they increased non-monotonically. They increased because they reflect the hyperbolic growth of population, but the hyperbolic growth is *not* characterised by a sudden surge. The population was increasing monotonically. Hyperbolic growth increases fast but monotonically over a short time and it is hardly a revelation that the combined intensity of human activities is now high and still fast-increasing.

We have to be careful when we analyse distributions illustrating human activities in recent years because these distributions are likely to reflect hyperbolic growth of population, which is monotonic but which creates an illusion of a sudden and sustained surge.

It is most disturbing to see so many misinterpretations of hyperbolic growth. Please analyse data carefully and the least you can do is to try to present them by using different displays, such as a semilogarithmic display or a display of their reciprocal values. Care should be also taken in separating effects associated with human activities from effects generated by other sources. It is essential to be guided by data and to avoid the strong temptation to see in data what we want to see.

However, there is a clear and distinct feature in the growth of population, which we could perhaps use as a marker for the approximate beginning of the modern stage of the Anthropocene. It is the current slow and ongoing transition to a new trajectory of growth, the transition, which commenced around 1950 (Nielsen, 2016e, 2017c; see also Figure 11). This transition is not characterised by a sudden acceleration to a new and faster trajectory but by a *slow* diversion to a *slower* trajectory, after just a minor and short-lasting initial boosting, which can be demonstrated only by a very close and careful analysis of data. It is a slow transition and it is not likely to be completed during the current century but might be completed during the next century. It is a rare event because in the past 2,000,000 years there were only two major transitions and one minor disturbance in the middle of the AD time (Nielsen, 2016e; see also Figure 11). This transition could be used to *define* (but not to determine) the approximate beginning of a new stage of the Anthropocene. The transition to a new stage of the Anthropocene might have started before 1950 but probably not far from that year. If we are looking for a unique marker of this transition we might use this unique feature in the growth of population.

If we accept that the current transition in the growth of population to a new trajectory can be used as marking the beginning of a new stage of the Anthropocene, then its beginning is now. We are in the middle of it but this transition is not likely to be completed until well into the next century. If we are looking for the stratigraphic markers of this apparent transition they might not be strong enough now but only in the future.

The search for the beginning the Anthropocene and for a proof that it is a geological epoch might be interesting but the far more important issue is how to survive our current intensive impacts on the environment, how to reduce them and how to create a sustainable future. We might be spending too much time trying to prove that the Anthropocene is the geological epoch but not enough time to find out how we can survive this new stage of human existence. Without our secure future, any intelligent form of life, who in some distant future might study the history of our planet might not see our Anthropocene as a new geological epoch but rather as a sudden extinction of an intelligent species, but not sufficiently intelligent to survive.

10. Summary and conclusions

The unconstrained growth of human population and economic growth are hyperbolic and they were hyperbolic most of the time in the past 2,000,000 years (Nielsen, 2016d, 2016e, 2016g, 2017c). Hyperbolic growth of population was first demonstrated for the world population during the AD time (von Foerster, Mora & Amiot,1960). I have extended this early study to the BC time, first to the past 12,000 years (Nielsen, 2016e) and later to the past 2,000,000 years (Nielsen, 2017c). Deevey (1960) was the first to notice that the growth of population in the past 1,000,000 years was in three stages. He was also the first to extend the estimations of the size of population below 10,000 BC. His estimations are accepted by the scientific community (see for instance Kapitza, 2006; Kremer, 1993; Livi-Bacci, 2007). I have demonstrated that these three stages were hyperbolic.

I have also analysed regional and global economic growth (Nielsen, 2016d) as well as regional growth of population (Nielsen, 2016g). All these studies lead to the same conclusion: the natural tendency for the growth of population and for the economic growth was to increase hyperbolically. They were never increasing exponentially as often believed. Hyperbolic growth was so stable and so consistent that in the past 2,000,000 years there were only two major transitions between hyperbolic types of growth and only one minor disturbance of hyperbolic trajectory, which caused only small shift in hyperbolic distributions.

Hyperbolic distributions are confusing because they can be slow over a long time and fast over a short time, creating the impression of being made of two distinctly different components governed by two distinctly different mechanisms of growth. These confusing features are currently erroneously interpreted, in the demographic and economic research, as representing two distinctly different stages of growth: stagnation and explosion (Nielsen, 2016a). However, hyperbolic distributions increase *monotonically*. There was never stagnation and never a transition to a new type of growth, which could be claimed as explosion ignited (McFalls, 2007) or detonated (Smil, 1999) by a new force of growth. The perceived explosion (the fast growth over a short time) is the natural continuation of hyperbolic growth.

The fundamental feature of the Anthropocene is that it represents strong anthropogenic impacts on the environment. Analysis of the growth of population in the past 2,000,000 years shows that, with just a few interruptions, the growth was *monotonically* hyperbolic. Human impacts on the environment prevailed over a long time and their evidence can be found in archaeological records. It was a gradual evolution on the canvas of the hyperbolic growth. Slowly and persistently the size of human population was increasing by following hyperbolic trajectories (see Figures 10 and 11). With this hyperbolic growth, human skills of interacting with the environment were increasing, from the Oldowan stone tool industry around 2.5 million years ago to the present highly advanced technology. Data suggest that the current strong anthropogenic impacts are the integral part of the much longer history of human existence and of the dynamics of the growth of population over a long time. The origin of the Anthropocene and its mechanism are firmly linked with the growth of population, which was consistently hyperbolic.

There were various well documented stages in the gradual development of technology and knowledge. There were probably also various stages of the Anthropocene. The gradual development of technology and knowledge is reflected in the gradually increasing anthropogenic impacts on the environment. The currently experienced strong impacts probably did *not* appear suddenly but are the results of a much longer evolution over a long time on the canvas of the hyperbolic growth of population. The Anthropocene appears to transcend the Pleistocene and Holocene epochs. Its modern stage is characterised by a rapid growth of population, rapid consumption of natural resources, rapid economic growth and the rapidly increasing anthropogenic impacts. All these features can be easily explained as the effects of the natural continuation of the monotonically increasing hyperbolic growth of human population.

What we experience now is both new and old. It is new because for the first time in human existence we are shaping our *global future* and perhaps even the future of our planet. But it is also old because our increasing impacts on the environment can be traced over a long time in the past, impacts which were developing slowly to reach the currently experienced high intensities.

It is still debated whether the currently experienced high intensity of anthropogenic impacts can be recognised as marking a new geological epoch. The beginning of this potentially new epoch is also hard to establish. The latest fast increase in the growth of population is nothing more than the natural consequence of the *monotonically* increasing hyperbolic growth. There was no "Great Acceleration" (Steffen, *et al.,* 2015), no significant and sustained boosting, no abrupt transition in the growth of population, which could be used as marking the beginning of the modern stage of the Anthropocene. The same applies to the economic growth, which could be interpreted as the reflection of our interaction with the environment and of our impacts on the environment.

There is, however, a feature in the growth of population, which could be used to determine the beginning of this new stage of anthropogenic impacts. It is the current *gradual and slow* transition in the growth of population to a new trajectory (Nielsen, 2016e). It is a rare and unique event because there were only two major transitions in the past 2,000,000 years and only one minor disturbance between AD 1195 and 1470. The current transition started with a *minor and unsustainable* boosting in the growth of population around 1950, the boosting, which can be revealed only by a close analysis of data. This transition diverts now the historical hyperbolic growth to a new but slower trajectory of unknown nature, and is expected to continue well into the next century (see Figure 12).

It is much more difficult to *determine* the beginning of the modern stage of the Anthropocene. New anthropogenic trends could be perhaps used for this purpose but we would have to have many examples of these trends to demonstrate a *clear shift* in the anthropogenic impacts. Stratigraphic evidence would be most desirable but it is still probably too early to detect a clear change in stratigraphic deposits.

However, is it really so vitally important to prove that the Anthropocene is a new geological epoch and to determine its beginning? It would be interesting if we could find such a proof but we might never find it. However, we can now at least understand why our impacts on the environment are so strong. They are strong because they are the results of the monotonically increasing hyperbolic growth of population and of the hyperbolic economic growth. The characteristic feature of hyperbolic growth is that it can increase fast over a short time.

Our fast-increasing impacts are correlated with the fast-increasing growth of population. There is nothing mysterious about the origin of the Anthropocene. We can explain it as the natural consequence of the hyperbolic growth. Exponential growth does not produce such fast-increasing effects and it is even inapplicable because human population was never increasing exponentially (Nielsen, 2016e, 2017c).

It appears that we might be worried too much about lexical semantics and we divert our attention from more important issues: our future, the future of our children and grandchildren, and the future of our more distant generations, if we and they are going to survive. Our planet might be destroyed by humans but it will continue its journey around the Sun and through space. However, our next generations, if they survive, might not be worried about the lexical semantics of the Anthropocene, about proving that it is a geological epoch and about determining its beginning. They will be probably worrying only about how to survive. However, if we work harder on creating a sustainable future we might still have teams of scholars in the future debating academic issues of the Anthropocene. On the other hand, we can now terminate all such discussion, quickly and irrevocably. All we need is for someone to be the first to press the button.

The *origin* of the Anthropocene is like the origin of a tree. The origin of a tree is in the seed planted in the ground because only then is the machinery hidden in the genetic code activated and only then does it come to life. The origin of the Anthropocene is in the human origin, in the origin of a species with a strong potential for the intellectual development.

The *beginning* of the Anthropocene is a slightly different matter. It is like the time of the beginning of a tree, but when does a tree become a tree? It all depends on how we define a tree.

Depending on our definition, we could claim that a tree is not always a tree but we could also claim that a tree is always a tree. We can define various stages of growth of a tree but they are only stages defined by us.

At a certain stage, a tree becomes strong and it looks like a tree, but this sentence is already incorrect because the growth of a tree is gradual. There is no sudden transition from a weak non-tree to a strong tree. There is no sudden transition to a strong "stage" because a tree does not grow in stages. The time of the beginning of a tree depends on our definition.

We could distinguish various stages of human impacts on the environment. We could distinguish various stages of the Anthropocene and we could claim that the current "stage" is distinctly different than all other stages and we would be right because never before did humans have such a strong impact on the environment. But when did this strong impact begin? We shall probably never know because as with the growth of a tree we do not know when a tree becomes a tree unless we define its beginning.

We can explain the origin of a tree and perhaps even its mechanism of growth but we cannot determine the beginning of the strong "stage" of a tree. We can only define it. Likewise, we can explain the origin of the Anthropocene and its mechanism but we shall probably never be able to determine the beginning of the "modern stage" of the Anthropocene. We can only define it.

This conclusion might not be liked by those who want to find the beginning of the "modern stage" of the Anthropocene but perhaps with this warning they might feel less disappointed if they cannot positively determine its beginning. Human impacts on the environment were developing gradually until they became strong, but we shall probably never know when precisely they became strong.

This brings us back to the crucial issue in this discussion. Perhaps we should be satisfied with understanding the origin of the Anthropocene and of its mechanism. Perhaps we should now understand that with the gradual growth of human population over the past 2,000,000 years, human impacts on the environment were also developing gradually. They were, no doubt, weak and even negligible for a long time but they were gradually increasing. Perhaps by understanding now the origin and the mechanism of the Anthropocene we shall stop worrying about trying to determine the beginning of its "modern stage" and focus our attention on how to make our future sustainable.

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