Invited lecture/Scientific contribution

The Story about One Island and Four Cities.

The Socio-Economic Soft Matter Model - Based Report.

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Abstract:
The report discusses the emergence of the Socio-Economic Soft Matter as the consequence of interactions between physics and economy, since the onset of modern times. First, using soft matter science tools, demographic changes since the Industrial Revolution times onset are tested. It is supported by innovative derivative-sensitive and distortions-sensitive analytic tools. All these revealed for population changes the Weibult-type powered exponential description, with the crossover to the lesser rising pattern emerging after the year 1970. Subsequently, population changes are tested for the Rapa Nui (Easter) Island model case and for four selected model cities where the rise and decay phases have occured. They are Detroit and Cleveland in USA and Łódź (Lodz, the former textile industry center), and Bytom (the former coal mining center) in Poland. The analysis shows universal scaling patterns for population changes, coupled to the scocio-economic background impact, revealing also the long-lasting determinism. Finally, sources of obtained universal behavior are discussed in the frame of the Socio-Economic Soft Matter concept.

Keywords: Demography; Socio-economy; Soft Matter; Weilbul distribution; Rapa Nui; Post-industrial cities

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1. Introduction

Nicolai Copernicus, Galileo Galilei, Isaac Newton, created the Modern Scientific Method. It is related to the non-speculative approach, with the experimental cross-verification of heuristic and thought concepts and the verbalization of results using a mathematical apparatus. It isn't easy to outline one of these giants, but Isaac Newton has to be appreciated for the Modern Science path's final shaping (Westfall, 1994). It led to unprecedented progress associated with new fundamental knowledge and innovations. The world entered a qualitatively new era of innovation-driven development, removing many problems that have plagued people for millennia. It is the onset of the Industrial Revolutions times (Groumpos, 2021).

Isaac Newton is mainly known for two monographs defining the basics of Mechanics (dynamics), Gravity, and Optics. He introduced the concepts of derivatives, differential equations, and integral analysis for a coherent and in-depth description. His indication that seemingly separate phenomena may have a common 'universal' source can be regarded as of particular importance. It was beyond any expectation at that times that a falling apple and the motion of planets and comets could reflect the same universal law of gravity, concluded in a simple, functional equation (Westfall, 1994).

Adam Smith, the 'father' of modern economics, was so overwhelmed by the concept of 'all-embracing universality' that he began to look for such phenomena in social and political economy-related phenomena (Smith, 1776, 2009). It is worth noting that Newton was also directly involved in such problems. Recognizing the great merits of his mind, Newton was nominated the Royal Mint head. His main task was preventing (dramatic) falls in currency value. Newton quickly realized that it was mainly due to a (very) physical action of forgers - scraping the edges of the coins, which reduced their weight. Newton solved the problem by developing an innovative hard metal alloy for coins and a serrated edge pattern for coins. Thanks to a multidisciplinary innovation combining physics, materials engineering, economics, and behavioral observations, Newton solved the grand socio-economic problem of the United Kingdom. This innovation is still in use (Westfall, 1994).

This report attempts to apply some basic concepts of physics, particularly soft matter physics, to discuss socio-economic and demographic model-system peculiarities and include universalistic ideas hidden behind them. To validate the application of physics to such issues, let's look at Newton's famous laws of motion from a socio-economic point of view:

1. When no force is acting on the body, or when these forces balance each other, it is at rest or moves at a constant speed along a straight line. Does it not also mean proportional, 'linear' development of the company, city, and even the state when positive and negative external factors balance each other?

2. The motion is related to the force F acting on a body with mass m, the measure of its inertia: $F = am$, where $a = const$ is the acceleration. In socio-economics, a parallel could be drawn by efforts invested into the activities of a large company with enormous structural inertia, compared to the rapid pro-market returns of medium and small companies.

3. There is no single force. Any action is accompanied by a reaction. The number of analogies in economics and everyday life is evident in the given case.

Three decades ago, Pierre Gilles de Gennes was awarded the Nobel Prize in Physics (1991) for another grand unification. He introduced the Soft Matter (SM) category linking many materials common in our surroundings. At first, it was related to polymers, liquid crystals, micellar systems, critical liquid,… (de Gennes et Badoz, 1996). Now, within Soft Matter also bio-systems, including colonies of bacteria and viruses, or food as the very complex soft matter case are considered (Drozd-Rzoska et al., 2002; Rzoska et al., 2011; Drozd-Rzoska et al., 2005a; Drozd-Rzoska et al., 2005b; Drozd-Rzoska, 2005; Drozd-Rzoska et al., 2006; Drozd-Rzoska et al., 2010). For the latter, one can recall popular products from milk, yogurt, mayonnaise, ketchup…. to pastes, cakes, and meat (Mezzenga et al., 2005). The Soft Matter concept has also been extended to topological (Serra et al., 2020) and quantum (Thedford et al., 2022) systems, offering new insight into fundamental Space properties.

What does Soft Matter mean? (de Gennes et Badoz, 1996). What can connect such apparently distinct systems? Only two common features are essential for universal characterizations and scaling patterns linking apparently distinct Soft Matter systems:

A. the dominance of collective, mesoscale 'structures', mainly correlated assemblies of atoms, molecules, or any other type of entities building a system/material.

B. extreme sensitivity to exo- and endo-genic impacts, which in fact, is the consequence of point (A).

In 2007, *The Guardian* magazine published a farewell to Pierre Gilles de Gennes in the following words (Goodby and Gray, 2007):

> *"…Newton of our time has died aged 74. He was awarded Nobel Prize, the Lorentz medal and Wolf prize for "discovering that methods developed for studying order phenomena in simple systems can be generalized to more complex forms of matter."*

In the recent work, the authors of this report put forward the thesis that one can consider the Socio-Economic Soft Matter due to the exemplary fulfillment of the above (A, B) general conditions. The global population $P(t)$ was chosen as a model system, and its evolution from the beginning of the Holocene / Anthropocene epoque, with the onset at $t_{ref.} = 12000BC$ was examined using Soft Matter tools (Rzoska, 2016; Rzoska and Drozd-Rzoska, 2022). The following scaling pattern for the population changes was revealed:

$$P(t) = p_0 exp\left(\pm\frac{\Delta t}{\tau(t)}\right)^{\phi} \qquad (1)$$

where $P(t)$ denotes population changes as the function of time, p_o is for the prefactor, $\tau(t)$ is the relaxation time constant, ϕ is the power exponent; $\Delta t = t - t_{ref.}$, and $t_{ref.}$ is the reference (onset) time; ± signs are related to the rise and decay process, respectively.

In Soft Matter systems, the exponent $\phi = 1$ indicates that the system is governed by a single relaxation time for dynamic processes or modes. For $0 < \phi < 1$, Expression (1) is named as the stretched relaxation relation, indicating a distribution of relaxation time (processes) (Drozd-Rzoska and Rzoska, 2011). In physicochemical systems $\tau\ (t) = \tau = const$ is assumed. Values related to $\phi > 1$ are for the 'compressed' relaxation processes, which are hardly obsered in physico-chemical systems. The exception is $\phi = 2$, which is equivalent to the normal (Gaussian) distribution (Rinne, 2008) of probability for different random allowed states of the system. It is notable that a similar expression as the one in Equation (1) resembles one of Weilbul's functions which are used to describe general probability distribution analysis for dynamic processes via different relaxation channels (Rinne, 2008; Rzoska and Drozd-Rzoska, 2011). This analysis is often implemented in various technological applications (Rinne, 2008), as well as in medicine Feroze et al, 2022), and microbiology (Buzrul, 2022). For the simplest case, i.e. for $\phi = 1$ in Equation (1), data analysis can be concluded using the following linear dependence:

$$lnP(\Delta t) = lnp_0 - \frac{1}{\tau}\Delta t \quad . \qquad (2)$$

The single-relaxation time dynamics, related to $\phi = 1$ in Equation (1), can be validated by the linear behavior in the plot defined by Equation (2). Following Equations. (1) and (2) $P(t = 0)/P(t = \tau) = e \approx 2.7$, i.e., the relaxation time τ is related to $1/e \approx 0.3678$ decrease of $P(t)$, with reference to the initial value. The convenient metric can be the parameter $\tau_{1/2} = \tau \times ln2$ describing the time required for 50% change in $P(t)$, which can be obtained by considering the relationship between logarithmic functions with different bases: $lnP(t) = log_e P(t)$ and $log_{10} P(t)$. The 'powered' Equation (1) with the arbitrary value of the exponent $\phi \neq 1$ can be related to $(1/e)^{1/\phi}$ decay (Rzoska et al., 1997; Rzoska and Drozd-Rzoska, 2022).

The nonlinear fitting is used for describing 'experimental' data by Equation (1) with the powered exponential function related to the exponent $\phi \neq 1$. Numerous practical implementations in soft matter systems showed that the direct nonlinear fitting using Equation (2) leads to surprisingly large errors for derived parameters. This basic problem can be avoided when considering the derivative of Equation (1) (Rzoska and Drozd-Rzoska, 2022):

$$\frac{d(lnP(t))}{dt} = \frac{1}{P(t)} \frac{dP(t)}{dt} = \pm \frac{\phi}{\tau} \Delta t^{\phi - 1} \quad . \tag{3}$$

The linearization of Equation (3) gives the following dependence (Rzoska & Drozd-Rzoska, 2022):

$$log_{10} \left| \frac{d(lnP(t))}{dt} \right| = log_{10}(\phi) + (\phi - 1) log_{10} \Delta t = a + s log_{10} \Delta t \tag{4}$$

where parameters $a = log_{10}(\phi / \tau) = const$, and $s = \phi - 1$.

The presentation of transformed $P(t)$ data via the plot $log_{10}[dlnP(t)/dt]$ $log_{10}\Delta t$ yields a linear behavior with the slope $s = \phi - 1$. The domain where Equation (1) can be applied is also indicated. By using the linearized analysis via Equation (4), one can reveal regions governed by different values of the exponent ϕ, and avoid the nonlinear fitting required for the direct analysis via Equation (1).

Recalling the discussion regarding the human population evolution, which is the key topic of the given report, the most significant model was introduced by Malthus (Malthus, 1803; Malthus and Stimson, 2018), who also declared the inspiration from Isaac Newton's legacy. They assumed that the constant rate of population changes and applied the derivative analytic tool introduced by Newton. It is called the Malthus model relation (Malthus and Stimson, 2018; Weil and Wilde, 2010; Kaack and Katul, 2013):

$$\frac{\Delta P(t)}{\Delta t} \rightarrow (\Delta t \rightarrow 0) \rightarrow \frac{dP(t)}{dt} = rP \qquad \Rightarrow \qquad P(t) = p_o exp(rt) \tag{5}$$

where $r = r(t) = const$ is the Malthus rate coefficient.

Equation (5) correlates with 'powered' Equation (1) for $\phi = 1$ and $t_{ref.} = 0$.

Malthus (Malthus, 1803; Malthus and Stimson, 2018), confronted the exponential population rise suggested by Equation (5) with the presumably linear increase of food resources expected in 19th century. The inevitable intersection of the trends of changes in the population and the number of resources indicated the unavoidable lack of the latter and, consequently, the certainty of famine and social disorder.

In the mid of 19th century, Velhulst supplemented the Malthus model focusing on the population growth in restricted resource conditions leading to the rise of the population and its subsequent stabilization. Such a situation can be functionalized as follows (Velhulst, (1847) 2022):

$$\frac{dP(t)}{dt} = rP\left(1 + \frac{P(t)}{K}\right) \quad \Rightarrow \quad P(t) = \frac{K}{1 + exp(-rt)(K - p_0)/p_0} = K\left[1 + exp(-rt)\frac{K - p_0}{p_0}\right]^{-1} \tag{6}$$

where *K* is the constant characterizing the number of available resources.

The third type of the Malthus-type models is related to the function correlated with Equation (1), introduced as the heuristic most straightforward extension of the basic Malthus relation (Equation (5)) (Golosovsky, 2009 and refs. therein):

$$P(t) = p_0 exp\left(rt^{\phi}\right) \quad . \tag{7}$$

It is applied via non-linear fit, generally in an arbitrarily selected time domain, which is always associated with large errors of derived parameters. The Weibull model function (Rinne, 2008; Golosovsky, 2009; Golosovsky, 2010) is often cited as a heuristic justification. The generalized Weibull-type equation (Equation (1)) (Rinne, 2008), supported by the distortions-sensitive and derivative-based analysis defined by Equation (4) was used to get new insight into the global population growth. It covers the entire period from the Holocene epoch onset.

Figure 1 presents the resume of these results, focused on the period after 1800, which covers the interest of the given report (Rzoska and Drozd-Rzoska, 2022). The result presented in **Figure 1** shows the non-monotonous pattern of global population rise based on Equation (1), governed by changes in the value of the exponent. Notable are periods where the increase of the global population slowed down, for instance, associated with World Wars I and II (WWI and WWII). Notable that for the latter, such trend started near 1930, which can be linked to the Grand Economic Depression, and terminated at 1948. The global population pattern changed from a fast to a slow rise near the year 1970. Is it the impact of 'cultural revolts' in 1968 (Gildea et al., 2013) and its consequences?

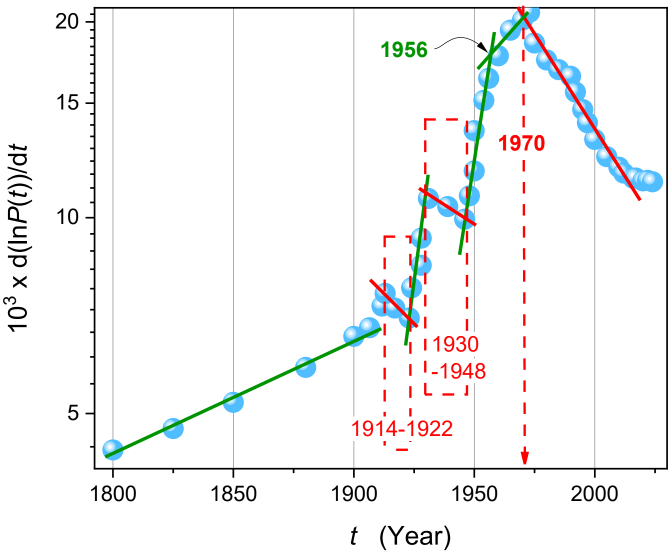

Figure 1: The plot showing the evolution of the World population using the Weibull-type Equation (1) and the distortions-sensitive analysis of its applicability (indicated by linear domain) via Equation (4). Slopes of lines are coupled to the power exponent ϕ in the Weibull-type Equation (1): slope of a $line = s = \phi - 1$. The behavior described by $s > 0$ (green lines) stands for the 'strong' rising rate of the population. The behavior described by $s < 0$ (red lines) stands for a significant decrease in the rising rate of the population. The crossover $s > 0 \rightarrow s < 0$ indicates the inflection between the mentioned trends. Characteristic years related to such changes are indicated. From (Rzoska and Drozd-Rzoska, 2022).

The Global Population exhibits the feature preferably expected for physical models – isolation from disturbing external factors, or at least their control. This work implements the concept of socio-economic Soft Matter for selected, characteristic, smaller-scale human populations, where the 'isolation' seems to be difficult, if possible at all.

Population changes in a size-restricted territory have to be inherently sensitive to internal factors, such as political and social conditions and available 'attractive' resources from food to energy. Such factors can also be non-material, as shown below. Notwithstanding, universal model-patterns also emerge in such apparently disturbed systems in the sub-global scale.

The discussion of this report starts from the Rapa-Nui (Easter Island case), which can be considered the canonic model for the development of 'small', isolated human populations.

2. Population Evolution : Microbiology parallel and the Rapa Nui (Easter Island) case

In the first centuries of the 1st Millennium, one of human history most significant exploration adventures occurred. Polynesians started grand oceanic travels, leading to the settlement of islands in the enormous area of the Pacific Ocean. The audacity and success of these efforts were and remain unprecedented. The expedition occurred on small but nautically perfect boats - catamarans and trimarans ensuring excellent journey stability. The exploration and settlement expeditions set off to other islands thousands of kilometers away without knowing whether they existed at journey terminals (O' Leary, 2021)

The enormous knowledge acquired at that time also supported the success of Captain James Cook grand expedition on the Endeavor ship, guided by Polynesian navigator Tupaya. The farthest island reached by explorers was Rapa Nui island, which European explorer Admiral Jacob Roggeeven called Easter Island in honor of his arrival there on Easter Sunday, April 5th, 1722. At that time, it was inhabited by 2 - 3 thousand people. Later studies showed that in the 16th and 17th centuries, the population of Rapa Nui was as high as 10-15,000 inhabitants. The next visit of Europeans was also of a research nature: in 1770, the expedition of Captain Felipe Gonzales de Ahedo, on the order of the viceroy of Peru, explored the island for 5 days (**O'Leary, 2012**).

In 1774, Captain James Cook visited the island during the grand Endeavor ship expedition. The visit resulted in excellent maps, descriptions of nature, comments regarding inhabitants, and communication on 'monumental' Moai statues on the coast. Captain Cook estimated the population between 700 and 200 inhabitants, with the latter being more likely. Between 1722 and 1770 on Rapa Nui, the final stage of the conflict between two existing clans known as 'short-ears' and 'long-ears' took place. It led to the disappearance of the 'long-ears' clan so completely that even no reliable genetic material remained. The remaining verbal tradition of the story on Rapa Nui indicates that the 'long-ears' could be been the ruling clan in the Island (O'Leary, 2021).

A special feature of the development of the human population on Rapa Nui, associated with the formation of an extraordinary civilization with exceptional achievements, was operating in conditions of isolation from the outside world, both from other Pacific islands and mainland South America. The settlement of Rapa Nui is associated with the last phase of the great oceanic expansion of the Polynesians. Shortly afterward, climatic conditions deteriorated periodically, affecting the limitation of expeditions on small and relatively fragile boats. In a small area of Rapa Nui, there was also rapid deforestation, especially the disappearance of palm trees. It meant there was no boats for grand ocean voyages and even fishing in the ocean surrounding Rapa Nui ceased to be possible. The inhabitants were cut off from the world's richest fish and food resources in the surrounding ocean. Notwithstanding, there have been indications that residents have developed 'ecological' gardens inside the island, largely solving the resource problem. Rapa Nui's population has grown to about ~10,000+ inhabitants (Hunt and Lipo, 2012; Lima et el., 2020; O'Leary,2021). However, from the mid of the 16th century, the global cooling of the climate, referred to as the Little Ice Age, took place. In Europe, its impressive manifestation was the winter freezing of the Baltic Sea, and traveled from Poland to Sweden using ice as the solid way.

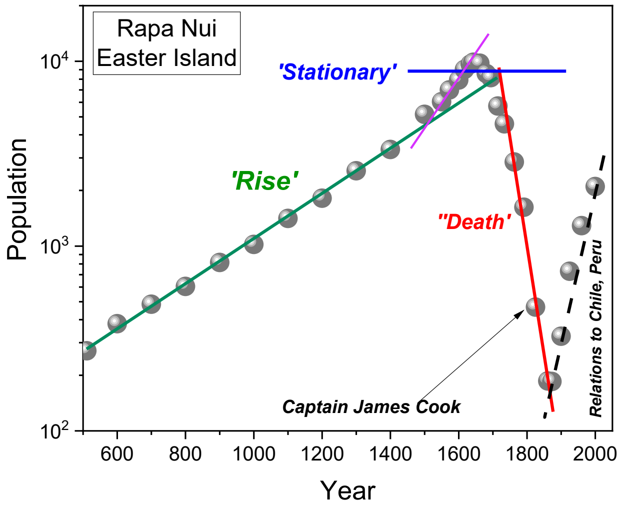

Figure 2: Changes of Easter Island (Rapa Nui) population since the hypothetical settlement till now. Basedmon data (O'Leary, 2021; Stevenson et al., 2006). The linear behavior is related to the Malthus model evolution, which is related to the exponent $\phi = 1$.

On Rapa Nui, it is a time of enormous intensification of the construction of increasingly monumental Moai sculptures - carved out of the volcanic rocks inside the inside the island and transported on wood logs to the coast (O'Leary, 2021). Such activities had to absorbed the relatively small population totally and aslo led to the final deforestation. It can be assumed that it was a kind of mystical rescue related to the growing problems resulting from unfavorable climate changes. Suddenly, violence 'explosion' led to the civilization collapse and rapid depopulation. It led to the disappearance of the 'ruling' clan.

Figure 2 presents population changes of Rapa Nui population in the semi-log scale, directly recalling the exponential portrayal via Malthus Equation (5) or Weilbull-type Equation (1) with the exponent $\phi = 1$. It is worth noting that there was an extra increase in population from about 1500 to the beginning of the 17th century. In Europe, it was a time of significant improvement in climatic conditions, which probably also had a global scale. The middle of the 17th century corresponds to the Little Ice Age and strong cooling.

On Rapa Nui there was an extremely brief stabilization of the population and a very rapid decline, which can be related to the reasons mentioned above. However, this picture may be oversimplified. The last decade studies have shown that Rapa Nui people have developed advanced eco-friendly gardens in the central parts of the island (Hunt & Lipo, 2012, Lima et al., 2020). There are indications that a giant tsunami wave (Pollard et al.) or extreme rains caused by so-called atmospheric rivers could sweep the Rapa Nui (Carvaja et al., 2021) and destroy food resources. The importance of the above factors can be significant and complicate the picture of Rapa Nui population changes.

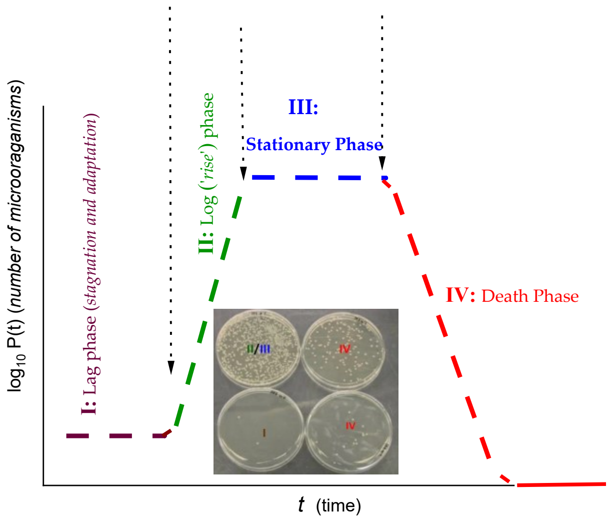

Figure 3: The illustration of the evolution of microorganisms population development in a closed container with a defined (limited) amount of food. The semi-log scale facilitates the manifestation of the single-relaxation (Equation (5) or Equation (1)) with the exponent $\phi = 1$. The photo presents E-Coli bacteria colonies in subsequent development stages (Rzoska et al., 2017).

Figure 3 shows changes of bacteria population in a container with a limited food amount. The semi-log-scale reveals the Malthus-type rise (phase II) followed by the stationary phase (phase III). Phases II and III together can be related to the Velhulst bimodal model (Equation (7)). Finally, the population disappeared (phase IV). The evolution of the bacterial population, which can also be considered the active Soft Matter, is similar to the population change in Rapa Nui.

However, there are some important differences. First, the stationary phase in **Figure 2** was extremely short. Second, the rise and decay were asymmetric for the Rapa Nui population (**Figure 2**). It can be related to the fact that the development and survival of the human population of Rapa Nui were strongly related to internal self-ordering. Its destruction occurred in a 'rapid' manner and in a short period. For bacteria population, such factor is obviously absent.

3. Population Evolution: hallmark post-industrial cities case

The question arises whether population changes evoking analogies to the dynamics of collective phenomena within Soft Matter Science may appear for human 'clusters', where interactions with the surrounding seem to be obligatory. To discuss this issue, the population development of a few hallmark post-industrial cities in Poland and the USA is discussed, from the beginning of the 19th Century until now. The differences between the situation in the respective countries are emphasized.

In the 19th Century, Poland did not exist, and its territory was divided between the three partitioning empires, Russia, Prussia / Germany, and Austria (Davies, 1996). For each of them, social and economic development followed a different path. Poland regained independence in 1918. It was 123 years of occupation by autocratic empires but also a time of nation formation. Unfortunately, Poland was located between them and became the arena of great wars caused by them. Poland was one of the main arenas of World War I (WWI), leading to enormous destruction and impoverishment. Twenty years later, in 1939, World War II (WWII) broke out, causing Poland one of the greatest human and material losses. After the war, there was a forced change of borders and the subjugation to the Soviet-Russian Empire, which terminated in 1990. The situation of Poland in recent centuries is perfectly reflected by the title of the recent monograph 'God's Playground. A History of Poland' (Davies, 2015).

In turn, USA is a country that, from its beginnings throughout the 19th century, until now, is growing harmoniously (Seavoy, 2006). The US participated in WWI and WWII as the most important contributor (Seavoy, 2006). However, these wars occurred outside the territory of the USA, and as a result, the country was becoming more powerful and more prosperous, which is perhaps an unprecedented 'paradox' in history. In the USA, a country on a continental scale, excellent pro-development conditions have always existed, mainly pro-economic, and pro-innovative, ... but also for personal freedom. The wars in which the USA participated, from the Civil War to WWI and WWII, not only did not ruin the country, but they became a fundamental factor intensifying its development (Seavoy, 2006).

What does the development of selected, specific cities look like in the context of such dramatically different countries? The main initial motive for their selection was the presence of a phase of strong population growth and then, after the stabilization phase, a rapid and significant decline in the population, which shows some similarity to model-patterns presented in **Figures 2 and 3**.

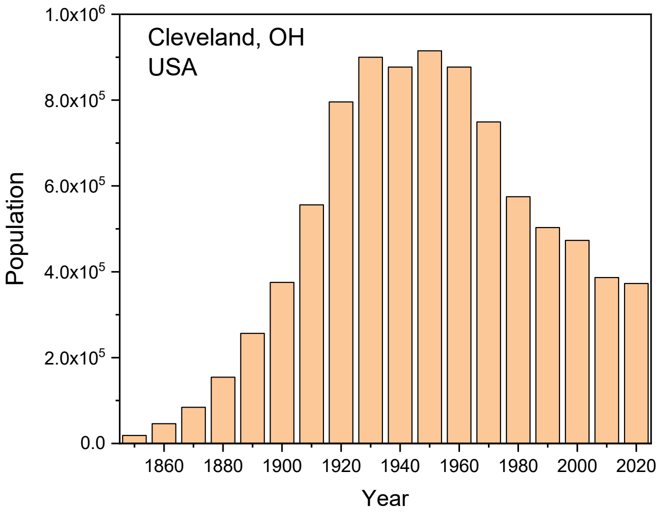

Figure 4. Population changes in Cleveland (Ohio, USA) in the classic bar presentation (based on Census, US: Cleveland, 2022).

Figure 4 shows population changes in Cleveland, Ohio (Census, US: Cleveland, 2022), in the semi-log scale, recalling the basic Malthus's behavior. Cleveland is a large city and harbor on the great Erie Lake coast. It developed as a significant transport hub. Its location, relatively in the far west of the USA, was of particular importance in the 19th and early 20th centuries, as it facilitated the transport of goods, ideas, and information by ships, which were then the dominant means of transport. Hence, for Cleveland the location constituted the crucial development motivator.

A significant driving force was also a variety of industries, primarily related to metallurgy. Cleveland has played the role of a financial, commercial, and scientific center (van Tassel & Grabowski, 1996). The latter is exemplified by three universities and the space research center. One cannot forget the famous Cleveland Orchestra. Despite such exciting characteristics, the population changes presented via the standard bar representation **(Figure 4)** show the stationary period after the substantial increase and a significant population decrease which continuous in the last 7 decades (!).

Figure 5 shows the analysis of population data from **Figure 4**, using the linearized, distortion-sensitive transformation of $P(t)$ data. via Equation (4). Following this dependence, linear domains validate the portrayal of $P(t)$ data by the powered Weibull-type exponential Equation (1), with slopes determing values of the power exponent ϕ.

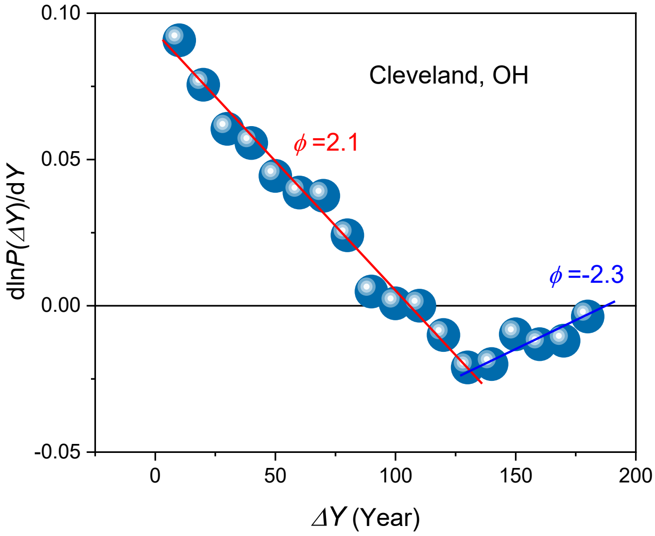

Figure 5: The linearized derivative-based analysis (Equation (4)) for the population changes $P(t)$ in Cleveland, Ohio, USA. The analysis is related to data given in **Figure 4**. Linear domains validate the portrayal via the empowered exponential Equation. (1), with value of exponents ϕ values given in the plot. *Y* stands for time (*t*).

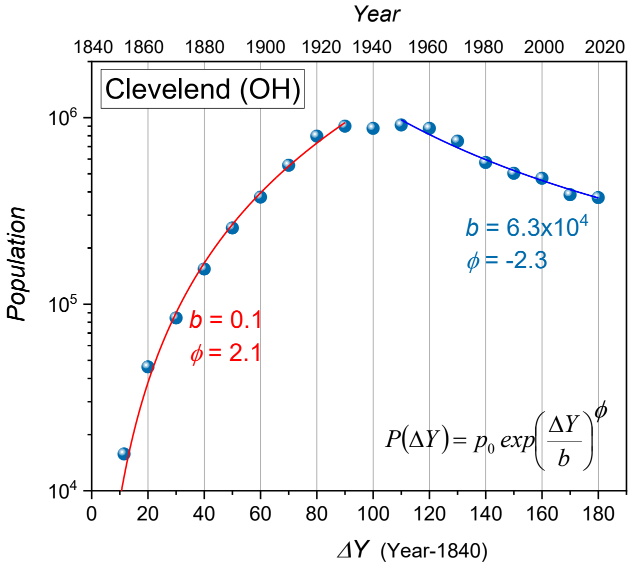

Figure 6: The semi-log presentation for the population of Cleveland, Ohio, USA, with the powered exponential portrayal of $P(t)$ changes via Equation (1). Note the link to parameters derived due to the analysis presented in **Figure 5**. *Y* stands for time (*t*).

Figure 6 shows the portrayal of population changes in Cleveland based on data presented in **Figures 4** and **5**. The long 'rise' and 'decay' domains are notable, with the stationary period between the years 1930-1950. The development of Cleveland was significantly motivated by the activity as the hub and exchange center for goods, information, and finances. The main factor which supported the development was initially the ship–based transport, possibly due to Great Lakes extending from the east to the far west of the USA. Rail transport rather complemented this at the beginning, but car/lorry transport and the development of the motorways/highways network changed the situation. The convenient port location ceased to be a crucial pro-development factor.

Figure 7 shows available population data for Detroit, Michigan, USA (Census US, Detroit, 2022) in the semi-log scale. It reveals the superior Mathus-type portrayal associated with the single-mode relaxation, linked to the exponent $\phi = 1$ in Equation (1), particularly since 1900. In an obvious way, the influence of the dominant industrial monoculture associated with the automotive industry is imposed here. However, the same development trend in Detroit seems to emerge already in the early 19th century. The thread of development determinism appears very interesting.

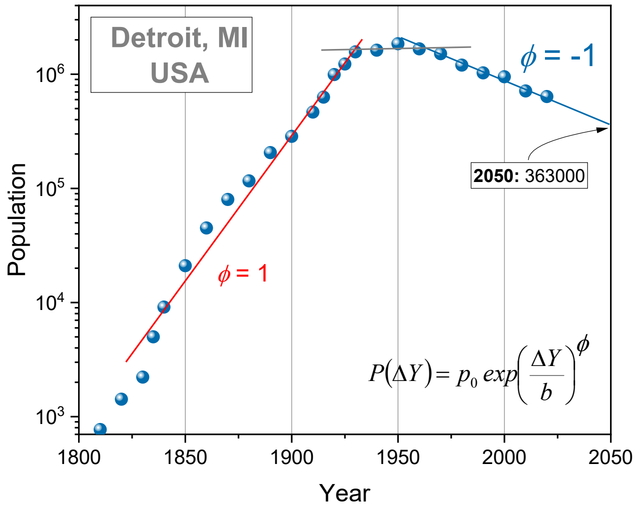

Figure 7: The population evolution in Detroit, Michigan, USA - in the semi-log scale. Solid lines represent the Malthus model type portrayal (Equation (5)), related to Equation (1) with the exponent $\phi = 1$.

Similarly to the respective pattern observed in Detroit, Michigan, USA (**Figure 7**), we found that based on the data from **(**Bytomski, 2022), a Malthus-type pattern associated with the exponent $\phi = 1$ in Equation (1) appears also in a very, very distant Bytom, Poland (**Figure 8).** In Bytom, the Malthus-type population increase extends from 1800 until 1980. It should be clarified here that Bytom is an old medieval town that turned out to be located in the center of one of the largest hard coal deposits in the world, of excellent quality. In the 19th century, it was the most important strategic energy resource. This factor defined the development of Bytom in the era of Industrial Revolutions, especially since the area of Bytom and Upper Silesia belonged then to the organizationally thriving Kingdom of Prussia, and then the German Kaiser's Empire. However, the history of the 19th and 20th centuries had a dramatic impact on Bytom. The development trend of Bytom was continuous despite (i) two world wars (WWI, WWII), (ii) changes in government nationality: until 1918 the city was under the German Kaiser's rule, from 1918 till 1945 it was included in the German Republic and in the Nazi-German state, (iii) since 1945, Bytom is a part of Poland, (iv) in years 1945/1946 the population exchange from German to Polish took place, (iv) in 19898/1990 the shift occurred in the political and economic system from quasi-communist to the real world 'capital' economic (Davis, 1996, Bytomski 2022). Bytom is an old city, but its rapid rise was associated with rich coal deposits. Reducing the population can be associated with a rapid decline in the role of coal as a strategic energy resource. This decline is also Malthusian-type. It should be mentioned, however, that there was also a constant factor throughout the period in question that reflected the nature of the local population of Upper Silesia, with its own language constituted by a dominant old Polish language, a strong influence of the German language and a strong internal cultural identification.

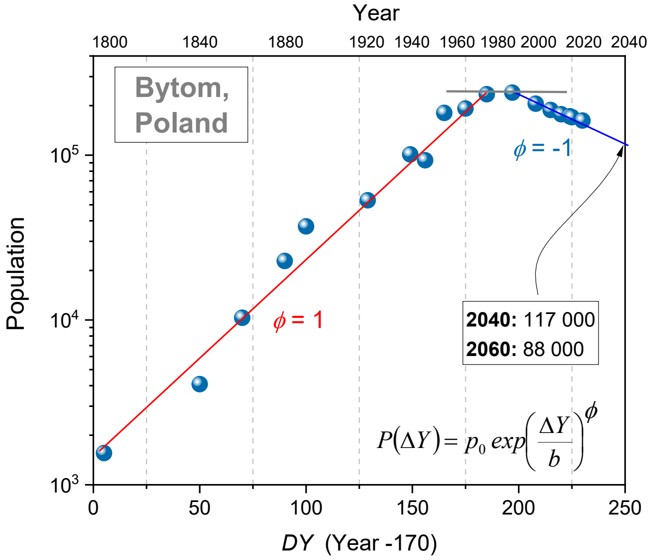

Figure 8: The evolution of the population in Bytom, Silesia, Poland - in the semi-log scale. Solid lines represent the Malthus-type portrayal (Equaton (5)), related to Equation (1) with the exponent $\phi = 1$. DY stands for time interval (in years).

In Poland, one of the large symbolic cities with a declining population and various social and economic problems is Łódź, located approximately 140 km east of Warsaw. The history of this city is peculiar. It developed from a small village near the border between Tsarist Russian and Prussian/German empires (Davies, 1997). The encouragement introduced by the Tsar of Russia led to the creation of an exceptionally rapidly expanding textile center, compared to Manchester UK, in the second half of the 19th century (Popławska and Muthesius, 1986).

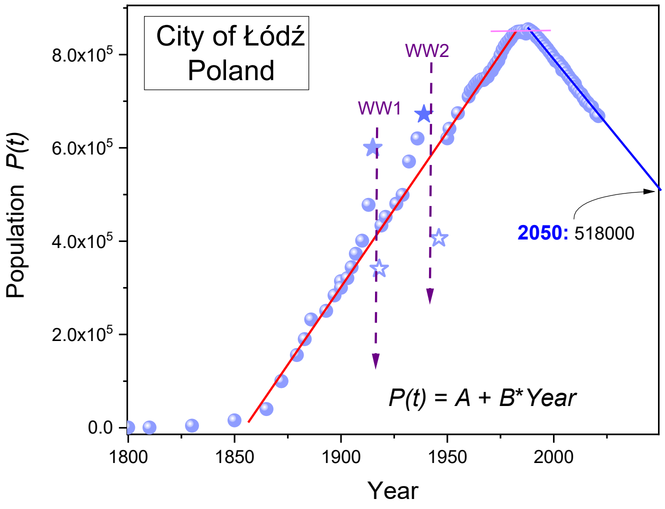

Figure 9: The evolution of the population in Łodź, Poland. Note the explicit linear dependencies during the increase and decrease of the population.

Figure 9 shows the extraordinary feature of the evolution of the population of Łódź. It increased linearly until the eighties, and later the explicitly linear decrease occurred. This suggests that the evolution is beyond the Malthus-type or powered-exponential patterns, which seemed to be universal (based on data avail at (Łódź w Liczbach, 2022). Notable, till the year 1915, Łódź belonged to the Tsarist Russian Empire (Davies, 1996), and the enormous economic capacity of the Empire stimulated its development. Huge human resources ready to work in the factories and the empire's market with proportionaly huge needs presented a significant impact.

In the period between 1905 and 1914, increasing economic freedom boosted Russia's economy, which seems to reflect in the accelerated population growth in Łodź. In 1915, the enhanced population rise could be associated with WWI refugees. It was followed by a massive compulsory evacuation when the Russian army left the territory of Poland. The population increase before WWII can be linked to the enormous poverty after the Grand Crisis. The population collapse during WWII (1946) reflects the holocaust of Jewish citizens. They constituted a significant part of Łódź population before WWII.

After WWII, Łódż returned to a mass textile production for the benefit of the Russian empire, at that time in the form of the Soviet Union. Poland was the Soviet Union-dependent country ruled by so-called 'Polish communists'. This trend changed in the second half of the 1980s when the communist system deconsolidated (Davies, 1996). Since then, a permanent decline in the population - also linear and still lasting – has occurred.

4. Conclusions

This work develops the socio-economic soft matter concept for discussing population changes in selected post-industrial hallmark cities. First, the reference case of Rapa Nui population, geographically isolated from any impact for centuries, was discussed. The analogy of the pattern observed for a colony of bacteria in a closed container with a limited amount of food/resources was indicated. For the Rapa Nui population development, the impact of global climate change and internal social ordering seems to be also significant. Subsequently discussed post-industrial (contemporary) cities are related to environmental interactions. Nevertheless, the characteristics of their development tracked by population changes show noticeable similarities to the model case of Rapa Nui.

For Detroit, the uninterrupted and continuous "Malthusian" exponential growth, described by Equation (1) with an exponent $\phi = 1$, took place. It suggests a single dominant process/motivator of dynamic changes, described by a single relaxation time. It was suggested that the reason for the decrease in the population was the decline in the automotive industry impact (Hyde, 2001) which began in the mid-1960s (**Figure 7**). The decline in the population may result from a decrease in the demand for labor in the automotive industry and a relative reduction in wages. The automation and the associated increase in productivity and increasing competition from Asian and European producers influenced the dominant industry in Detroit, and consequently, the population of this largely mono-cultural city has decreased.

Population changes in Cleveland, Ohio are specific: both rise and decay have the Weibull-type dependence described by Equation (1) with the exponent $\phi \approx 2$. The city emerged as a significant transport and exchange hub due to its favorable location on the great Lake Erie coast. Its location, supported by various industries, has shaped the city's success for decades and led to strong population growth. However, since 1950, the population of Cleveland has continued to decline, which was also reflected in economic aspects. The 'powered' exponential Equation (1) describes both the increase and the decrease, which suggests that it is a multi-channel process related to a set of relaxation times. Let us recall that the economy of Cleveland was multi-faceted from the beginning but dependent on a single factor - a great harbor (van Tessel and Grabowski, 1996). The weakening of this driving-force factor had influenced the development trends of other 'development channels', affecting the development and population. Since the mid-1950s, the final dominance of trucks and modern railways transport has occurred in the USA (Seavoy), 2006), reducing Cleveland's role as the transport hub.

Note that Detroit and Cleveland are cities (i) located in the USA, which is a country of model freedom and business support (Seavoy, 2006), (ii) it is characterized by unprecedented mobility of the workforce (Seavoy, 2006), (iii) the permanent increase of the US population has taken place (Seavoy, 2006).

The perfectly one-channel 'Malthusian' population dynamics also appear in Bytom (Poland), a city distant from Detroit (**Figure 8**). In Bytom, essential changes related to the nationality of citizens, governments, and the political system took place. They do not seem to be significant for the population changes. One may suggest that the driving force of the changes derive from huge deposits of high-quality coal. The depletion of deposits and unfavorable long-term price changes in the international coal market from the mid-1980s (Galata, 1997) limited the role of coal mining. The decay of the dominant economic stimulants started, resulting in a single exponential population decay in Bytom (**Figure 8**). It is worth recalling that population changes reflect the city's socio-economic attractiveness.

In Poland, Łódź symbolizes a city with problems associated with political system changes (Galata, 1997). Like Detroit and Bytom, Łódź was the city created and shaped for decades by a single industry related to large weaving and textile factories. Until WWI and after WWII, the production of this industry was consumed, motivated by the enormous needs of the Russian empire, no matter whether governed by Tsaristic imperialists or Soviet-dependent so-called ‘communists’ (Davies, 1996). At the end of the 1980s, this factor practically disappeared, and competitive and cheaper textiles from Asia appeared, which won the market in Poland. Soon later, weaving factories collapsed (Szpakowska-Loranc and Matusik, 2020). Thousands of people lost jobs and the life-path concept. Often, they worked in textile factories for generations (Szpakowska-Loranc and Matusik, 2020). New work positions emerged very slowly. Such a situation caused a vast and probably still existing trauma that was strengthened by textile factories employing mainly women.

As stated above, the city's population changes can be associated with its economic attractiveness. The last factor should be treated not only in terms of salaries but also of expenses related to the life quality, price of housing, accessibility, and cost of social facilities, transport, etc. According to the authors, the specific dynamics of population changes in Łódź can be explained by developing Equation (1) in Taylor series for $\beta = 1$:

$$P(t) = p_0 exp\left[\pm\left(\frac{\Delta t}{\tau(t)}\right)^{\beta=1}\right] \Rightarrow P(t) = p_0\left[1 \pm \frac{\Delta t}{\tau} + \frac{1}{2}\left(\frac{\Delta t}{\tau}\right)^2 \pm \frac{1}{3}\left(\frac{\Delta t}{\tau}\right)^3 + \cdots\right]. \tag{8}$$

where $P(t)$ represents population changes in selected units: thousands, millions, … of inhabitants. With relatively small values of the argument or the influence of a parameter shaping a given trend, we can neglect the terms of higher order to get the linear evolution of the population

$$P(t) \approx p_0\left[1 \pm \frac{1}{\tau}\Delta t\right] . \tag{9}$$

Such a situation may occur when the impact of the dominant economic force on the surrounding is realized via non-interacting ‘channels’, with negligible feedback interactions between them. As a result, additional power terms in Equation (8) are not activated, and the development of the city, also measured by the evolution of the population, is linear as given in Equation (9). In the opinion of the authors, the hypothetical minimal feedback effects that can create pro-development added value in Łódź can be associated with the unique situation that the dominant driving force were women, for all decades accepting worse working conditions, payment, and social environment (Szpakowska-Loranc and Matusik, 2020).
This situation is dramatically opposite to Bytom or the Upper Silesia region in general, where the authorities have always been afraid of the wrath of miners who were decisive men, moreover, they were well organized (Upper Silesia, 2023). So, isn't the still difficult situation of Łódź a legacy of decades or even centuries of economic exploitation of women, who were the main working force in textile factories?

In summary, it can be stated that some aspects of the development of selected urban centers can be considered as a Socio-Economic Soft Matter entity, with the population dynamics described and explained by models that are relevant also in Soft Matter Science. The environment seems to be a kind of averaging factor - in Soft Matter it can be described as a 'mean field approximation', which results in a qualitative simplification of the description of important processes. In such an approach, population changes are 'managed' not only within an example of bacteria in a container or population in the Rapa

Nui island but also by the existence of an 'attractor' in a given city, attracting people from outside the city, which in turn may start to leave the city when the attractor weakens or disappears completely if a much stronger other attractor appears nearby. In Poland, an example of such a new strong attractor can be Warsaw, located relatively close to Łódź, currently well connected, with attractive jobs for various professions. An interesting and surprising factor may be the 'dominant trend' in urban development appearing exceptionally early. An example is Detroit, where the car industry emerged at the beginning of the 20th century, but the same development trend has existed since the beginning of the 19th century. According to the authors, this issue may be related to the question of why the center of innovation in the automotive industry was established in Detroit? Maybe the reason was the pro-innovation potential there that led to it? Another somewhat surprising issue is the practical symmetry of the population growth and decline trends and the durability of the latter despite significant, positive countermeasures that are taken, for example, in Cleveland and Łódź. The last factor is the universality of the processes because the cities considered here were subjected to qualitatively different historical and socio-economic conditions.

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References

1. Bytomski (2022): https://forum.bytomski.pl/historia-miasta-i-zabytki/114729-zmiany-ludnosc-bytomia. Accessed: 28.02.2023
2. Buzrul S. The Weibull Model for Microbial Inactivation. Food Engn. Rev. 2022; 14: 477-485. DOI: https://doi.org/10.1007/s12393-021-09291-y
3. Carvaja M, Winckler P, Garreaud R, Igualt F, Contreras-López M, Averil P, Cisternas M, Gubler A, Breuer WA. Extreme sea levels at Rapa Nui (Easter Island) during intense atmospheric rivers. Natural Hazards 2021; 106:1619–1637. https://doi.org/10.1007/s11069-020-04462-2
4. Census, US: Cleveland, Ohio (2022): https://www.census.gov/quickfacts/clevelandcityohio Accessed: 28.02.2023
5. Census, US: Detroit, MI (2022): https://censusreporter.org/profiles/16000US2622000-detroit-mi/. Accessed: 28.02.2023
6. Chadwick O, Puleston C, Ladegofed T, Stevenson C. Variation in Rapa Nui (Easter Island) land use indicates production and population peaks prior to European contact. Proc. Natl. Acad. Sci. 2015; 112: 1025-1930. DOI: 10.1073/pnas.1420712112
7. Davies, N. Heart of Europe: a Short History of Poland. Oxford Paperbacks, Oxford. 1996. ISBN: 978-0192851529
8. Davies N. God's Playground. The History of Poland. Oxford University Press, Oxford, 2015). ISBN: 9780199253395
9. de Gennes PG, Badoz J. Fragile Objects: Soft Matter, Hard Science, and the Thrill of Discovery. New York: Springer Verlag,1996
10. Drozd-Rzoska A. Pressure dependence of the glass temperature in supercooled liquids. Phys. Rev. E. 2005; 72: 041505. DOI: https://doi.org/10.1103/PhysRevE.72.041505
11. Drozd-Rzoska A, Rzoska SJ. Complex relaxation in the isotropic phase of n-pentylcyanobiphenyl in linear and nonlinear dielectric studies. Phys. Rev. E. 2002; 65: 2885-2889. DOI: https://doi.org/10.1103/PhysRevE.65.041701
12. Drozd-Rzoska A, Rzoska SJ, Pawlus S, Zioło J. Complex dynamics of supercooling n-butylcyanobiphenyl (4CB). Phys. Rev. E. 2005a; 72: 031501. DOI: https://doi.org/10.1103/PhysRevE.72.031501.

13. Drozd-Rzoska A, Rzoska SJ, Imre, AR. Liquid–liquid phase equilibria in nitrobenzene–hexane critical mixture under negative pressure. Phys. Chem. Chem. Phys. 2005b; 6: 2291-2294. DOI: https://doi.org/10.1039/B315412B
14. Drozd-Rzoska A, Rzoska SJ, Pawlus, S, Tamarit, JL. Dynamics crossover and dynamic scaling description in vitrification of orientationally disordered crystal. Phys. Rev. B. 2006; 73: 224205. DOI: https://doi.org/10.1103/PhysRevB.73.224205
15. Drozd-Rzoska A, Rzoska SJ, Pawlus S, Martinez-Garcia JC, Tamarit JL. Evidence for critical-like behavior in ultraslowing glass-forming systems. Phys. Rev. E 2010; 82: 031501. DOI: https://doi.org/10.1103/PhysRevE.82.031501
16. Feroze N., Tahir U., Noor-ul-Amin M., Nisar K.S., Algahtani M.S., Abbas M., Ali R., JIrawattanapanit A. Applicability of modified weibull extension distribution in modeling censored medical datasets: a bayesian perspective. Sci Rep 2022, 12: 17157. https://doi.org/10.1038/s41598-022-21326-w
17. Galata S. The Transformation of Poland's Economic System: 1985-1995. Canadian Slavonic Papers / Revue Canadienne des Slavistes 1997; 39, 27-45. https://www.jstor.org/stable/40869888
18. Gildea R, Mark J, Warring A. Europe's 1968: Voices or Revolt. Oxford Univ. Press, Oxford, 2013. ISBN: 9780199587513
19. Golosovsky, MA. Models of the World human population growth- critical analysis, (2009). eprint arXiv:0910.3056
20. Golosovsky MA. Hyperbolic growth of the human population of the Earth: analysis of existing models", in "History and Mathematics", pp. 188-204. Ed. by Grinin, L., Herrmann, P., Korotayev, A., and Tausc A, Uchitel Publishing house, Volgograd, Russia (2010); available at arXiv:0910.3056v1
21. Goodby JG, Gray GW. Obituary: Pierre Gilles de Gennes, Mon. 4th Jun, 2007 edition. Available from: https://www.theguardian.com/science/2007/jun/04/guardianobituaries.obituaries. Accessed: 28.02.2023
22. Groumpos P. A critical historical and scientific overview of all industrial revolutions. IFAC . 2021; 54: 464-471. https://doi.org/10.1016/j.ifacol.2021.10.492.
23. Hunt TL, Lipo CP, Ecological catastrophe, collapse, and the myth of ecoside on Rapa Nui (Easter Island). PERC Res. Pap. 2012, 12: 21-44. DOI: https://dx.doi.org/10.2139/ssrn.2042672
24. Hyde CK. Detroit the Dynamic": The Industrial History of Detroit from Cigars to Cars. Michigan Hist. Rev. 2001; 27, 57-73. https://doi.org/10.2307/20173894
25. Kaack LH, Katul GG. Fifty years to prove Malthus right. Proc Natl Acad Sci U S A. 2013; 110: 4161-4162. DOI: https://doi.org/10.1073/pnas.1301246110
26. Lima M, Gayo EM, Latorre C, Santoro CM, Estay SA, Cañellas-Boltà N, Margalef O, Giralt S, Sáez A, Pla-Rabes S, Chr. Stenseth N. Ecology of the collapse of Rapa Nui society. Proc. R. Soc. B 2020; 287: 20200662. DOI: https://doi.org/10.1098/rspb.2020.0662
27. Łódź w liczbach (eng: *Lodz in numbers*) (2022): https://uml.lodz.pl/. Accessed at 28.02.2023
28. Malthus TR, Stimson SC. An Essay on the Principle of Population: The 1803 Edition, New Haven: Yale University Press, 2018. DOI: https://doi.org/10.12987/9780300231892
29. Mezzenga R, Shurtenberger, P, Burbidge A, Michel M. Understanding foods as soft materials. Nature Mater. 2005; 4: 729–740. DOI: https://doi.org/10.1038/nmat1496
30. O'Leary D. Rapa Nui, Easter Island. Puerto Rico: Floricanto Press, 2021. ISBN: 978-1099750267
31. Pollard J, Paterson A, Welham K. Te Miro o'one: the archaeology of contact on Rapa Nui (Easter Island). World Archaeology 2010; 42: 562-580. https://doi.org/10.1080/00438243.2010.517670
32. Popławska I, Muthesius S. Poland's Manchester: 19th-century industrial and domestic architecture in Lodz, J. Soc. Architect. Hist. 1986; 45, 148-163. DOI: https://doi.org/10.2307/990093
33. Rinne H. The Weibull Distribution: A Handbook (1st ed.). Chapman and Hall/CRC. 2008. DOI: https://doi.org/10.1201/9781420087444.
34. Rzoska AA. Econo- and Socio- Physics based Remarks on the Economical Growth of the World. Turk. Econ. Rev. (TER) 2016; 3: 82-89. Available at : http://www.kspjournals.org/index.php/TER/article/view/615
35. Rzoska SJ, Drozd-Rzoska A. Dual field nonlinear dielectric spectroscopy in a glass forming EPON 828 epoxy resin. J. Phys.: Condens. Matter. 2011; 24: 035101. DOI: 10.1088/0953-8984/24/3/035101.
36. Rzoska AA, Drozd-Rzoska A. Global Population Growth as Socio-Economic Soft Matter System Dynamics Evolution. Physics. Soc-ph. 2022; arXiv:2209.01407 [physics.soc-ph]. DOI: https://doi.org/10.48550/arXiv.2209.01407
37. Rzoska, SJ, Zioło, J, Drozd-Rzoska A. Stretched relaxation after switching off the strong electric field in a near-critical solution under high pressure, Phys. Rev. E 1997; 56: 2578-2581. DOI: https://doi.org/10.1103/PhysRevE.56.2578.
38. Rzoska SJ, Rosiak E, Rutkowska M, Drozd-Rzoska A, Wesołowska A, Borszewska-Kornacka, MK. Comments on the high pressure preservation of human milk. Food Sci. and Nutr. Studies 2017; 1: 17-28. DOI: https://doi.org/10.22158/fsns.v1n2p71
39. Seavoy R. An Economic History of the United States: From 1607 to the Present. Routledge, New York, 2006. ISBN: 978-0415979818

40. Serra F, Tkalec U, Lopez-Leon L. Topological Soft Matter. Front. Phys. 2020; 11: 1- 108. DOI: https://doi.org/10.3389/fphy.2020.00373
41. Smith A. The Wealth of Nations. Digireads,UK, reprint edition, 2009: reprint from the first edition in 1776.
42. Szpakowska-Loranc E, Matusik A, Łódź – Towards a resilient city. Cities. 2020; 107: 102936. DOI: https://doi.org/10.1016/j.cities.2020.102936
43. Stevenson CM, Jackson TL, Mieth A, Bork H-R, Ladefoged TN. Prehistoric and early historic agriculture at Maunga Orito, Easter Island (Rapa Nui), Chile. Antiquity 2006; 80: 919-936. DOI: https://doi.org/10.1017/S0003598X00094515
44. Thedford RP, Yu F, Tait WRT, Shastri K, Monticone F, Wiesner U. The promise of soft matter enabled quantum materials. Adv. Mat. 2022; 35: 2203909. DOI: 10.1002/adma.202203908
45. Upper Silesia. https://en.wikipedia.org/wiki/Upper_Silesia. Accessed 15.03.2023
46. Van Tassel DD, Grabowski JJ. The Encyclopedia of Cleveland History, Indiana University Press; Cleveland, 1996. ISBN: 978-0253330567
47. Velhulst PF. Deuxieme Memoire sur la Loi d'Accroissement de la Population. Mémoires de l'Académie Royale des Sciences, des Lettres et des Beaux-Arts de Belgique (1847); 20: 1-32. https://eudml.org/doc/178976.
48. Weil DN, Wilde J. How relevant is Malthus for economic development today? Amer. Econ. Rev. 2010; 100: 378–382. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4112762/
49. Westfall RS. The Life of Isaak Newton. Cambridge Univ. Press. 1994. DOI: https://doi.org/10.1017/CBO9781107050334