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Technological Growth as Exponential Growth, Democratic Theory as Cultural Diffusion, and Scientific Growth as Cumulation, Diffusion, and Innovation

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Abstract

I seek to evaluate popular claims that science and technology grow exponentially in democratic and non-democratic societies: This includes the capacity for science to grow exponentially and related questions of how to distinguish scientific growth from technological growth, including "Moore's Law." This paper seeks to place patterns of societal evolution in relation to each other, including scientific growth, technological growth, and how cultural diffusion and access to symbolic systems and media (access to Japanese or Chinese scripts, or Latin, Greek, or Arabic scripts, or GUIs) contribute to scientific growth and technological growth in democratic and non-democratic societies.

The paper includes a series of provocative thought experiments that seek to show that established knowledge of physics or other branches of science do not double every fifteen years to twenty years, or 20 years to 25 years, or at some other exponential rate of growth. I seek to show that the established knowledge of textbook physics, including the classical mechanics of Galileo and Newton, does not double every fifteen years to twenty years, and that, more generally, the established knowledge of different branches of science, including discoveries or sets of ideas that are considered revolutionary in nature, from Mendeleev's Periodic Table, to Mendel's Theory of the Particulate Nature of Genetic Inheritance, to Watson and Crick's discovery of the double-helical structure of the DNA, does not double every fifteen years to twenty years.

Keywords: ***Exponential growth; Moore's Law; Technology; Science; Culture; Democratic societies; Non-democratic societies***

Introduction

It is sometimes claimed by scientists, social scientists, engineers, technologists, media theorists, businesspeople, and also philosophers of science that technology grows exponentially, and that science grows exponentially [1]. Harvard scientist Edward O. Wilson, for example, claims that "scientific knowledge doubles every fifteen years to twenty years," and that science grows exponentially like technology or technological growth [2].

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Economist Helena Lastres comments on the “Evolutionary Approach to Technical Change” that the “evolutionary approach” rejects economic theories that consider technology and technological innovation as a “given” in advanced societies with some form of economic capitalism or economic policies for economic growth.

“Evolutionary theory rejects the *ceteris parabis* models which assume that technology is exogenously given (as in traditional economic growth theory) and could be treated as a ‘residual,’ and defines inventions and innovations as, at least partly, endogenous activities within the economy.”

Instead, this paper attempts to consider the nature of technological growth and scientific growth in democratic and non-democratic societies, and attempts to place patterns of technological growth and scientific growth in relation to patterns of human social evolution including cultural diffusion and access to particular cultural patterns like writing systems and symbolic systems (such as access to Latin, Greek, or Arabic writing systems, or Japanese or Chinese writing systems).

The advancement of science and technology are relevant to the growth of organizations, corporations, and democratic societies and non-democratic societies: In this paper, I seek to evaluate popular claims that technology grows exponentially, that science grows exponentially, and that, since democratic societies usually enjoy more cultural diffusion than non-democratic societies, they have more technological growth and scientific growth. I shall focus on the question of the capacity for science to grow exponentially and the related question of how to distinguish scientific growth from technological growth, including "Moore's Law" and the claim that there is non-cumulative or revolutionary change in science. Thus, as suggested, this paper seeks to place patterns of human social evolution in relation to each other, including scientific growth, technological growth, cultural growth, and how cultural diffusion and access to particular cultural patterns like writing systems and symbolic systems (such as access to the Latin, Greek, or Arabic scripts, or Japanese or Chinese writing systems) contribute to scientific growth, technological growth, and cultural growth in democratic societies and non-democratic societies.

Materials and Methods

Theory

How different technologies have different rates of technological growth, including discussions of “Moore’s Law” and Tesla Motors: Scientist Edward Wilson claims that technological growth is exponential, and that scientific growth is exponential as well: “High technology runs at a comparable pace alongside . . . science.” Wilson also claims that exponential growth in science “will continue through most of the 21st century,” though at some point scientific growth will plateau or “level off.”

In the journal Nature, scientist Alexander Szalay and former Microsoft scientist Jim Gray claim that, “the amount of scientific data is doubling every year,” and that, “as data volumes grow, it is increasingly arduous to extract knowledge” [3]. Alexander Szalay and Jim gray comment that, because of the growth in the amount of data, “scientists must labour to organize and reduce the data producing smaller data sets that eventually lead to the big picture.”

It is an interesting question of how to evaluate the nature of technological growth. At least since William Ogburn’s work on the subject earlier in the 20th century, it has been recognized that technology or material culture potentially grows exponentially in the evolution of human societies [4].

From the perspective of William Ogburn and others, the macroscopic perspective of the evolution of human societies in the evolution of the human species, technological growth is exponential or potentially exponential.

However, from a more “fine-grained” perspective, technologists sometimes comment that different technologies grow at faster rates than others [5, 6]. G.E. Moore, co-founder of the Intel Corporation, sought to establish what has been called “Moore’s Law,” that computer processing power doubles every two years. (Moore initially suggested that the processing power of computer chips doubled every 18 months, and revised his estimation to every two years) [7]. In 1977, Robert Noyce, former Chairman of the Board at Intel Corporation, described the success of “Moore’s Law”: “with circuits containing 218 (262,144) elements available, we have not yet seen any significant departure from Moore's law. Nor are there any signs that the process is slowing down, although a deviation from exponential growth is ultimately inevitable. The technology is still far from the fundamental laws of physics: further miniaturization is less likely to be limited by the laws of physics than by the laws of economics” [8]. There were celebrations of “40 years of Moore’s Law in 2005,” and celebrations of 50 years of “Moore’s Law” in 2015, although the journal IEEE Spectrum originally titled their interview with Gordon E. Moore, “The Man Whose Name Means Progress” by another title, “The Law that’s Not a Law” [9, 10]. This is presumably because of continued projections that Moore’s Law will not continue indefinitely in the computer industry. Gordon E. Moore himself gave an interview in 2010 claiming that “Moore’s Law” was “dead,” and that computing power would continue to increase (though not at the earlier exponential rate of growth described by “Moore’s Law” for 40 years to 50 years) [11].

“Moore’s Law” is commonly viewed as a model for the suggestion that science and technology grow exponentially. However, computer scientists T. Lewis and G. Denning comment that, clearly, not all technologies grow exponentially: “Moore’s Law is not available for every technology. We might wish for automobiles that travel 1,600 miles on a gallon of gasoline—approximately six doublings (26) better than today’s most efficient automobiles” [12]. The following generations of automobiles would be expected to get 3,200 miles per gallon, 6,400 miles per gallon, 12,800 mpg, 25,600 mpg, etc.

As Gordon E. Moore stated at a press conference in 2005 celebrating 40 years of “Moore’s Law”: “If the automobile industry moved this fast, your car would move at a million miles per hour and it would get 50,000 miles per gallon” [13].

Thus, gasoline or diesel fuel vehicles do not demonstrate exponential growth in their horsepower, torque, or fuel efficiency over the longer term: In the event that gasoline or diesel fuel automobiles doubled in their horsepower every generation, the vehicles would travel faster than planes, rockets, European Space Agency spacecraft, National Aeronautics and Space Administration spacecraft, or the spacecraft and satellites of other nation-states or nation-state agglomerations. In the short term, in their early stages, new technologies may grow exponentially, and then plateau or level off in their growth, power, and efficiency.

However, from Ogburn’s perspective, over the longer term, new technologies may emerge that replace or provide alternatives to existing technologies, that may give the appearance of exponential growth: The electric vehicles of Tesla Motors, for example, in effect travel more than 1600 miles per gallon; however, in terms of their everyday usability, Tesla Motors cars may travel approximately 200 miles to 250 miles before requiring re-charging, and the new generation of Tesla Motors vehicles are supposed to be able to travel 400 miles before requiring re-charging.

This is potentially related to Ogburn’s idea of the exponential growth of societies over the long term of the evolution of human societies; that is, that there may be exponential growth in one kind of technology or set of technologies, then a plateau or slowing rate of growth, and then the discovery or invention of another technology or set of technologies that may replace the earlier technology or set of technologies and their growth rate.

Before Ogburn, Henry Adams, in The Education of Henry Adams, published in 1907 and 1918, proposed a “Law of Acceleration” related to technological growth [14]. He used multiple examples of technological growth from the 19th century, including stupendous growth of locomotive trains and train lines in the United States, Europe, and elsewhere, and also the exponential growth rate in the production and use of coal throughout the world: “society by common accord agreed in measuring its progress by the coal-output.

The ratio of increase in the volume of coal-power may serve as dynamometer. The coal-output of the world, speaking roughly, doubled every ten years between 1840 and 1900.” Moreover, Adams summarized, the efficiency of coal production increased three to four times over the same time period: “in the form of utilized power, for the ton of coal yielded three or four times as much power in 1900 as in 1840.” By Ogburn’s more general perspective of the evolution of human societies of Homo Sapiens from about 500,000 years ago to the Neolithic Revolution 10,000 years ago, to the Industrial Revolution of the 18th, 19th, and 20th centuries, to the “Information Age” Post-Industrial Revolutions of the 20th and 21st centuries, the technological growth of earlier technologies or sets of technologies, when they slow in their growth or reach plateaus, are replaced at some point by new inventions or combinations of technologies that set a new pace of exponential technological growth.

In the area of scientific publications, sometimes treated as a measure of scientific productivity, it has been alleged that scientific growth is exponential. However, this may only be the case in the early stages of scientific growth in particular branches of science or sub-branches or sub-fields of science. In 2012, the number of peer-reviewed scholarly journal publications, including science journals, was 28,100.15 if the growth rate of scientific journals was exponential, the number of scientific journals in 2012 might have been in the hundreds of thousands or millions, depending on the start date at which the doubling rate was expected to begin. Instead, as suggested, early exponential growth in scientific publications is a short-term process limited to the early stages of growth of new branches or sub-branches of science, or when a revolutionary advance or invention in an established branch or sub-branch attracts short-term exponential growth before returning to the earlier rate of growth (i.e., returning to the “equilibrium” after the “punctuation”), leveling off to a lower rate of growth compared to the short-term exponential growth, reaching a plateau, or possibly contracting somewhat as a sub-branch of science compared to other branches or sub-branches.

Lewis and Denning discuss Moore’s Law, and how the processing power of computer chips has doubled approximately every two years at least since the 1950s; however, has the efficiency and usability of commercially available computers doubled every two years?

Since the development of commercially available personal computers in the 1980s, has the usability and efficiency of personal computers doubled every 2 years, or even with every generation of personal computers?

In this case, the answer is no: Instead, the introduction of Graphical User Interface (GUI) software by Apple and Microsoft for commercial and business computing increased the usability and efficiency more than the doubling of the processing power of computer chips; advances in the software of Graphical User Interfaces, such as Microsoft PowerPoint and Office Applications, and graphical user interface software for Apple I phones, iPads, and other computers and devices have increased the usability of commercially available computers more than the doubling of the processing power of computer chips. Thus, exponential growth may sometimes be a “mirage,” and other kinds or types of advances in technology or science may be more important or fundamental for efficiency, productivity, usability, or societal, technological, or scientific growth (as in advances in software versus the doubling of computer chip processing power ever 2 years, or particular advances or inventions in science or technology versus the sheer growth in the number of scientific articles or scientific journals in a branch or sub-field).

Technological growth as exponential growth, and Scientific growth as something Different: Edward Wilson is a brilliant scientist, and his book Letters to a Young Scientist has numerous forceful statements and advice for young scientists. He states that, “ideas in science emerge when some part of the world is studied for its own sake.” Wilson also evaluates and criticizes theoretical models in the biological sciences: “The annals of theoretical biology are clogged with mathematical models that either can be safely ignored, or, when tested, fail.” Wilson also consistently rails against religious and political authorities that refuse to test ideas publicly, and supports scientists, scientific journals, and scientific institutions that test their ideas and theories against empirical reality. Wilson thus publicly endorses democratic theory that claims that democratic societies enjoy more technological growth and scientific growth than non-democratic societies because they have more cultural diffusion (and that individual freedoms such as freedom of the press, freedom of expression, and freedom of religion are related to democratic societies having more cultural diffusion, and, usually, more ideological diversity and cultural diversity than non-democratic societies) [15-17].

Wilson also encourages scientists to take advantage of the freedom of expression made available by the internet, a degree of freedom of expression he views as consonant with science, scientific values, and scientific progress: “The internet and all other accoutrements of digital technology have rendered communication global and instant . . all published knowledge in the sciences and the humanities will be available in a few keystrokes . . . science and technology hide . . . no secrets” [18].

How is it possible to evaluate the claim that science grows exponentially like technology and technological growth? There are at least two ways of evaluating the claim made by scientists like Edward O. Wilson and others that, since science is related to technology, science grows exponentially like technology.

That is, it is possible to evaluate this claim quantitatively, and qualitatively and quantitatively,

- Do the number of scientific publications grow exponentially, including over the long-term? As reviewed in the previous sections, social scientists have sought to show that while scientific publications in particular fields or sub-fields may grow exponentially in their early phases, the number of scientific publications does not grow exponentially over the long term.
- Does the established knowledge of physics or other branches of science double every fifteen years to twenty years, or 20 years to 25 years, or at some other exponential rate of growth? I seek to show that the established knowledge of textbook physics, including the classical mechanics of Galileo and Newton, does not double every fifteen years to twenty years, and that, more generally, the established knowledge of different branches of science, including discoveries or sets of ideas that are considered revolutionary in nature, from Mendeleev’s Periodic Table, to Mendel’s Theory of the Particulate Nature of Genetic Inheritance, to Watson and Crick’s discovery of the double-helical structure of the DNA, does not double every fifteen years to twenty years.

Thought Experiments on the Nature of Knowledge

A doubling rate of articles qualifying the ideas of Galileo's discoveries or Mendeleev's discoveries are not doubling rates in the nature of scientific knowledge; instead, they are doubling rates in scientific publications; General Laws and Principles of Science, like Galileo's Laws, Mendeleev's Laws, Hubble's Law, or Darwin and Wallace's Principles of Natural Selection do not grow exponentially like, say, coal production in the 19^{th} century or computer processing power described by Moore's Law.

It is possible to ask, what would it mean if the established knowledge of classical physics, including all of the branches and subfields of classical physics, were to double every fifteen years to twenty years? What would textbooks in classical physics and modern physics be like if their knowledge doubled every fifteen years to twenty years? Did the knowledge of your physics textbook of this year, including all of the branches and subfields of classical physics and modern physics, double from the physics textbook you had fifteen years to twenty years ago? The answer to this question is no.

When scientists such as Harvard professor Edward Wilson or others speak of "exponential growth" in science they may be referring to short term exponential growth in scientific publications; however, this is not exponential growth in scientific knowledge itself.

Thus, there is a simple thought experiment may distinguish differences in the nature of knowledge: say there is exponential growth in the number of publications on Galileo's classical mechanics over a period of time, though the publications largely explicate, test, re-establish or hone or qualify Galileo's classical mechanics. Does this imply or result in,

- Exponential growth in the nature of science and scientific knowledge, or only,
- Exponential growth in the number of publications on a particular subject or set of discoveries and ideas in a branch of science? Say there is exponential growth in the number of publications on Mendeleev's periodic table: Does this imply or result in,
- Exponential growth in the nature of science or scientific knowledge, or,
- Only imply or result in exponential growth in the number of scientific papers, books, and publications instead of exponential growth in the nature of scientific knowledge in a particular branch of science? The exponential growth in the number of publications on any scientific discovery or set of ideas does not necessarily imply or result in exponential growth in the substantive nature of science or knowledge, i.e., the intellectual content or substantive nature of knowledge of your physics textbook (including Newton's Laws, Galileo's classical mechanics, or the Compton effect), chemistry textbook (including Avogadro's Law, Mendeleev's periodic table, or Linus Pauling's principles of chemical bonds), or biology textbook (including Darwin and Wallace's law of evolution by natural selection, Mendel's laws of genetics, Kimura's neutral theory of evolution, or Watson and Crick's model of the universal nature of genetic information) does not double every fifteen years to twenty years.

Thus, the established knowledge of classical physics, the established knowledge of physics from early modern Europe through the end of the 19th century, does not double every fifteen years to twenty years; moreover, the established knowledge of post-classical 20th century physics and contemporary physics does not double every 15 years to20 years. The established knowledge of physics doubling every fifteen years to twenty years is not possible, and the established knowledge of physics of other branches of science growing exponentially or doubling at a fixed rate is not possible.

Galileo's Laws, Newton's Laws, Mendeleev's Laws, Darwin and Wallace's Principles of Natural Selection, or Hubble's Law do not double every fifteen years to twenty years or at other rates of exponential growth, like, say, coal production did in the 19th century through part of the 20th century or computer processing power described by Moore's Law; consequently, scientific knowledge does not grow exponentially; this is a law of social evolution; scientific knowledge may grow cumulatively, like the gathering of facts and the cumulation of empirical discoveries; by comparison, some technologies may grow exponentially, like periods of the exponential growth of coal production in the 19th century and part of the 20th century, or the exponential growth in computer processing power recognized as "Moore's Law": scientific publications in different sub-fields of science may grow exponentially during different periods of time; however, this does not necessarily imply exponential growth in the nature of knowledge, only exponential growth in the number of publications over specific intervals of time [19-21].

Economist Lastres comments that science and technology have a "strong reciprocal interaction," however, Lastres, following Christopher Freeman, rejects the argument that since technology is sometimes dependent on discoveries and advances in science, that science grows exponentially like some technological patterns: "science and technology cannot be treated as the same thing."

Results

Tripartite process in the growth of science in human social evolution

Since scientific knowledge does not grow exponentially, though technological invention does sometimes grow exponentially, a three-stage process in the growth of scientific knowledge may be identified;

- scientific knowledge does not grow exponentially: scientific knowledge may be relatively static without growth in knowledge, may reduce or collapse during medieval periods or Inquisitions, or scientific knowledge may grow cumulatively by adding facts, testing propositions and ideas, qualifying or extending existing knowledge, and by adding new discoveries though not as an exponential process;
- by comparison, sometimes, technology and technological growth does grow exponentially, such as coal production in the 19th and 20th centuries or exponential growth in computer processing power described by Moore's Law (elaborated above);
- by comparison, sometimes, scientific discoveries and scientific theories "jump" or "fly" ahead of established knowledge in science or established methods or practices in technology and invention; (i.e., scientific knowledge may develop as a non-cumulative process when there are discoveries or sets of ideas that are revolutionary in nature, though do not involve or imply exponential growth per se: examples include Mendeleev's periodic table of elements, Edwin Hubble's discovery that the galaxies are separating from each other at accelerating rates instead of being static in relation to each other, Watson and Crick's discovery of the double-helical structure of the DNA, or earlier scientific revolutions, such as those of Copernicus, Galileo, or Newton).

This criticism and elaboration of this three-stage or tripartite process also may be relevant to the interaction and intersection of science, ideas, and the business world in the "information age."

Thus, this paper also places claims and ideas on the nature of non-cumulative or the revolutionary nature of change in science in relation to patterns in human social evolution. Like qualitative changes in physical phenomena that are related to quantitative differences in heat and energy, i.e., qualitative changes from solids to liquids to gases, there are qualitative differences in the nature of science, scientific knowledge, scientific growth, and technological growth that are related to their quantitative growth; the nature of exponential or potential exponential growth in technology is not identical or even nearly identical to cultural growth in science (symbolically: technological growth, “TG” is not equal to scientific growth, “SG,” or, “TG ≠ SG”); moreover, science, as a form of symbolic culture, usually 'lags' behind incessant or near incessant technological change and growth; from the standpoint of the philosophy of science, this is a rule instead of a law: that is, this is a pattern with specific exceptions, i.e., scientific growth, “SG,” is less than “TG,” technological growth, or, “SG<TG”; however, there are exceptional cases of scientific theory and scientific discoveries “jumping” for “flying ahead” of established technology or established methods or practices in technology and invention; that is, there are special cases in the growth of science in which the nature of scientific change is not cumulative, and not exponential over the long term, though “jumps” or “flies” ahead of established knowledge in science and established methods or practices in technology and invention; however, as suggested, revolutionary discoveries like Mendeleev’s Periodic Table or Watson and Crick’s model of the double-helical structure of the DNA and theory that it implied a universal nature of the DNA as genetic information across cellular life, do not imply that scientific growth is identical to the exponential growth of technology; thus, in the history and development of scientific knowledge there are cases and periods of scientific growth that are non-cumulative and “jump” or “fly” ahead of established knowledge and cumulative growth; this is when scientific growth is greater than cumulative growth, or, “SG>CG”; however, “revolutionary” and non-cumulative scientific growth is not equal to exponential growth, “SG ≠ EG”; thus, revolutionary and non-cumulative discoveries and advances in science are different than and not equal to exponential patterns of growth in technology and invention (e.g., exponential growth in 19th century and 20th century coal production, 19th century and 20th century train and freight train growth and productivity, or 20th century and 21st century computer processing power as described by Moore’s Law); “revolutionary” and non-cumulative scientific growth in discoveries or new sets of ideas or theories may “jump” or “fly” ahead of existing or established knowledge or established methods in technology or invention, however, these do not sustain exponential growth, i.e., discoveries like Galileo’s laws of classical mechanics are not reproduced at an exponential rate every fifteen years to twenty years; discoveries like Mendeleev’s periodic table are not reproduced at an exponential rate every eighteen months or two years (like Moore’s Law), five years, ten years, or fifteen years to twenty years; discoveries like Watson and Crick’s discovery of the double-helical structure of the DNA are not reproduced at an exponential rate every two years, five years, ten years, or fifteen years to twenty years; or, discoveries like Edwin Hubble’s discovery of the accelerating separation of the galaxies in the universe are not reproduced at an exponential rate every two years, five years, ten years, or fifteen years to twenty years.

Discussion

Democratic theory as cultural diffusion, and its relationship to scientific and technological growth

Democratic theory is also related to this body of knowledge: democratic theory postulates that democratic societies have more technological growth and inventions than non-democratic societies or different types of authoritarian societies, and that democratic societies have more scientific growth and discoveries than non-democratic societies or different types of authoritarian societies; democratic theory also attempts to explain how and why societies with authoritarian political or military leadership may increase their productivity in invention, science, and technology when they are put into contact with more “democratic” social conditions, like the decentralized and plural political and jurisdictional structure of early modern Europe and Western societies distributed across hundreds or thousands of different political jurisdictions before the French and American political revolutions, or the cultural contact and cultural diffusion languages, technologies, and international markets to authoritarian and isolated Japan in the 19th century, or the cultural contact and cultural diffusion of electronic communications, international markets, and technologies to China with the economic liberalization of one-party state Communist China post-1975; thus, the body of knowledge that is called or referred to as "democratic theory" in popular politics and academia is supported by the conditions of democratic societies supporting the conditions of cultural diffusion, i.e., the accessibility and spread of ideas and inventions, and the accessibility and spread of science, scientific knowledge, discoveries, technology, technological practices, methods, and inventions; democratic laws and practices such as individual freedoms, freedom of expression, freedom of religion, and freedom of the press sustain or are supposed to sustain patterns of cultural diffusion related to the greater spread, accessibility, and growth of ideas and inventions in democratic societies compared to non-democratic societies;

Thus, in world history, democratic theory seeks to explain why several Catholic societies that originally led Europe in scientific discovery and technological achievements had different or reduced patterns of scientific and technological growth as a consequence of Inquisitions and counter-reformations that banned books, tortured natural philosophers as religious skeptics, and tortured potential followers of the natural philosophers or early scientists: the Portuguese explorers were the first to circumnavigate the globe, the Spanish and Italian explorers are credited with discovering the Americas, the generation of Italian physicists with Galileo and Torricelli that are credited with inventing modern experimental physics, and the Polish astronomer Copernicus that studied music, law, and science is credited with the first scientific revolution in predictive astronomy that jumped ahead of the "scientific revolution" of Claudius Ptolemy's of the ancient world; the Inquisitions and counter-reformations of Catholic countries involved torture and attempted to ban the works of prominent natural philosophers and religious philosophers that were either involved in the scientific revolutions of early modern Europe or supported their revolutionary ideas and practices: the works of Galileo were banned, the works of Copernicus were banned; the exploratory and explicatory works Giordano Bruno were banned; the scientific, mathematical, and philosophical works of Descartes were banned; the works of Erasmus on natural philosophy and secular education were banned; the works of Erasmus on religious education, his translations of the New Testament into Latin, and his commentaries on this translation on the New Testament were banned; and the works of many other figures of science, natural philosophy, and religious philosophy were banned under threat of arbitrary torture and punishments in Catholic countries that previously had led all of Europe in scientific discoveries and technical achievements; several countries completely ignored or repulsed attempts by the Catholic Church to ban or place the works of Galileo, Copernicus, Descartes, and Erasmus and others on the Index of banned books: these included most Protestant countries and also Catholic France that never banned the works of Descartes, Erasmus, Newton, Galileo, or Copernicus; the former Spanish Netherlands converted to Protestantism or mostly to Protestantism and ignored or repulsed attempts to ban the works of natural philosophers and religious philosophers that threatened religious authorities of foreign countries; Belgium, that mixed Protestant and Catholic populations ignored or repulsed attempts to ban the works of prominent natural philosophers and religious philosophers; England and Scotland largely converted to Protestant sects and ignored or repulsed attempts to ban the works of Galileo and Newton, Erasmus and Descartes, Copernicus and Giordano Bruno, and other prominent natural philosophers and religious philosophers that were banned in several nation-states on continental Europe during the Inquisitions and counter-reformations that lasted through the 19^{th} century in many parts of Catholic continental Europe; the early colonies of the United States and the United States post the 1787 Constitution ignored or repulsed attempts by religious and political authorities of continental Europe attempting to ban prominent works by natural philosophers and religious philosophers.

Democratic theory thus explains the reversal of several patterns related to the relative decline in technical achievements of Catholic countries versus Protestant countries and secular Catholic France: Italy, Portugal, Spain, and Poland briefly led all of Europe in scientific discoveries and technical achievements: as reviewed, there were considerable technical and scientific achievements of Catholic countries, such as Galileo's experimental physics, Copernicus' predictive astronomy, the Portuguese explorers circumnavigating the globe, or the Spanish and Italian explorers, credited by George Washington or others, of discovering the Americas; however, the Inquisitions that lasted in Catholic countries through the 19th century (except for secular Catholic France) explain, from the point of view of democratic theory, why industrial revolutions happened more quickly and earlier in France, Great Britain, the Netherlands, Belgium, and the United States in the 18th and early 19th centuries than Italy, Spain, Portugal, or Poland; (German areas are mixed cases since Germany was disaggregated across hundreds of city-states and principalities, and would lose talent to France, Great Britain, the US and other countries before the 'revolutions' of 1848 that officially ended inquisitorial and other policies of torture in German city-states and principalities); Inquisitions and counter-reformations reduced the cultural diffusion of ideas and scientific and technical achievements by banning books and torturing subjects; natural philosophers, talent, followers of natural philosophers, and religious dissenters also fled to Great Britain, France, and the US, and, in smaller numbers to the Netherlands and Belgium; as suggested, these countries also enjoyed industrial revolutions before Spain, Portugal, Italy, Germanic states, and Poland; moreover, they enjoyed more scientific achievements and adapted and absorbed more scientific achievements than countries that were affected by Inquisitions and counter-reformations, i.e., when a small number of Italian scientists contributed potentially revolutionary discoveries such as Volta and Galvani on electricity, these discoveries were not initially absorbed by Catholic societies such as Italy, Spain, Portugal, Poland or authoritarian Germanic societies that did not attempt to reduce arbitrary torture and punishments until after the political 'revolutions' of 1848 across Europe; instead, the discoveries of Volta and Galvani were utilized and absorbed by rapidly industrializing France, Great Britain, the Netherlands, Belgium, and the United States.

In principle, democratic theory, or aspects of democratic theory related to cultural diffusion, seeks to explain differential patterns of scientific growth in the world history of Europe, the Muslim world and the Ottoman Empire, and the medieval and early modern Chinese Empires; in the medieval period, the Muslim world and China were technologically and scientifically ahead of Europe; during the so-called Middle Ages or medieval period, there was a greater flow of technologies, trade, and ideas across Muslim societies and China than from and across European societies and foreign societies; within the Muslim world, there was greater contact and flow of ideas and translations from scientific and technical achievements of the ancient world, including the ancient Greek world, than from the ancient Greek world to Europe and Western societies; these patterns began to reverse with the revolution in cultural diffusion of Fibonacci simplifying Arabic numerals for use in European universities, trade, science, and invention; by the 16th and 17th centuries, wars and ideology may have played a role in reversing these patterns in Muslim societies and China, as European societies, distributed across thousands of different decentralized jurisdictions, including city-states, principalities, bishoprics, universities, and kingdoms, during the Renaissance and Enlightenment periods, began absorbing more culture, technology, and inventions from foreign societies, and also from translations from the ancient Greek world, than Muslim societies and early modern China; from the point of view of democratic theory and cultural diffusion theory, the decentralized political and military geography of early modern Europe, including thousands of different political, legal, and military jurisdictions, explains why patterns of cultural growth, scientific growth, and technological growth began to reverse in the late Middle Ages, Renaissance, and Enlightenment in Europe and Western societies compared to the Muslim world and early modern China; (from the point of view of organization theory, or the economic-organizational theories of Karl Marx and Karl Wittfogel, many of the small European political, legal, and military jurisdictions were too small to extract, exploit, and use resources and inventions and technologies for large-scale political, economic, and political uses, compared to, say, the Ottoman Empire or early modern China; however, some of the small political and military jurisdictions of early modern Europe, like the Netherlands or Italian city-states were initially more successful in producing resources and extracting taxes than larger early nation-states, such as France or Britain; moreover, many of the inventions and organizational-legal inventions of small city-states and bishoprics like the Netherlands, the bishopric of Liege, or Italian city-states were absorbed or adapted by larger nation-states, particularly France, Britain, and the US).

If science is conceived as a kind of culture, does science sometimes "lag behind" technological invention, and sometimes "jump" or "leap" ahead of technology?

Frameworks of cultural anthropologist Alfred Louis Kroeber and social scientist William Ogburn: Ogburn and Kroeber view science as culture, though their theories of scientific and cultural growth have different points of emphasis. By Ogburn's theory, technology is material culture, scientific instruments and tools are material culture, and the body of scientific knowledge in different branches of science are kinds of symbolic culture: since science is a kind of symbolic culture it is expected, like other cultural patterns, to "lag" behind incessant or near incessant technological growth; however, Kroeber (and the biographers of great scientists) recognize that in science and cultural phenomena more generally, there are sometimes advances in science and culture (including scientific theory and entrepreneurialism) that "jump," "leap," or "fly" ahead of the social patterns of their contemporaries, including the technology and technological growth of their contemporaries.

William Ogburn was the first social scientist to claim that cultural growth is exponential or potentially exponential over the generations of human evolution (instead of merely focusing on rates of technological growth over short time spans like the Industrial Revolution): that early simple societies for most of human evolution, from archaic Homo Sapiens approximately 500,000 years ago to 10,000 years ago had relatively small amounts of culture and technology, and slow rates of cultural accretion, until the Neolithic revolution of established settlements 10,000 years ago and the emergence of established settlements and writing systems as early as 5,000 years ago; since the Neolithic revolution, post-Neolithic societies have had much faster rates of cultural and technological growth compared to pre-Neolithic societies, as the base of culture, including a larger base of combinations of existing technologies and inventions, have increased. Societies that have participated in the industrial revolution have had much faster rates of technological and cultural growth than pre-industrial societies; thus, Ogburn suggested that material cultural growth or technological growth have been exponential from the earliest simple societies to contemporary post-industrial societies; thus, while Darwin sought to establish the gradual nature of the evolution of biological species, Ogburn (called a "Darwin of the social sciences") showed that material cultural growth or technological growth is exponential or nearly exponential in the evolution of human societies from archaic Homo Sapiens to most contemporary societies around the world; from a more microscopic or "fine-grained" perspective, the development and success of different patterns in symbolic culture may facilitate or play a role in technological invention and growth ("hardware"), and the diffusion and spread of material culture or technology.

In what languages, mathematical systems, or symbolic systems (“software”) do individuals or groups contribute potential scientific and technological revolutions? For Copernicus, Galileo, and Newton, exposure or fluency in Latin, Greek, Euclidean geometry, and Arabic numerals may have been cultural prerequisites for their scientific revolutions, and they may have been cultural prerequisites for technological advances and revolutions by their contemporaries (as the graphical user interface and contemporary computer software may be prerequisites that facilitate contemporary scientific and technological advances; in the medieval period, Europe and the West were technologically behind the Arab and Muslim worlds, and also China, before Fibonacci’s revolution in cultural diffusion simplifying and spreading Arabic numerals and the decimal system to Europe and the West). From Ogburn’s perspective, the greater political diversity and linguistic diversity of Europe contributed to the greater cultural diffusion of ideas and technologies compared to the early modern Muslim world or China, once Europe had reached a level of development that it could compete with the Muslim world and China. From the standpoint of human evolution, the invention of new technologies that may have exponential rates of growth, like increasing computing power described by “Moore’s Law,” are special cases of Ogburn’s Principle. There are debates in the literature as to whether some sets of technologies, and also societies themselves, may plateau in technological development and growth. However, brief technological plateaus may be overtaken by unexpected inventions and combinations of technologies over the longer term. From the standpoint of human biological evolution, cultural growth is potentially exponential or nearly exponential over the generations of human evolution, although in particular centuries or millennia there may be fits and starts, plateaus, and also acceleration and stupendous leaps and jumps.

Moreover, from the standpoint of Ogburn’s theory, the intellectual content of science is symbolic culture, and the instruments and technological products of science are material culture; thus, the earlier statements that the established knowledge of classical physics does not double every fifteen years to twenty years may be evaluated from the standpoint of Ogburn’s theory: the symbolic culture of classical physics, or the intellectual content of classical physics, does not double every fifteen years to twenty years since it is impossible for the established knowledge of classical physics or even post-classical physics to double every fifteen years to twenty years; from the standpoint of Ogburn’s theory, the instruments of science are part of larger patterns of technological growth in the societies of which they are a part, and thus the instruments and technologies of science usually grow faster than the intellectual content or established knowledge of science; there may be incessant technical advances and improvements in instrument design and productivity, like technical advances and improvements in telescopes for astronomy; the philosopher Quine might say that the access to technology and instruments, like powerful telescopes, was relatively constant in many countries around the world; however, the discoveries and theoretical interpretation of Edwin Hubble was not constant across the national or international scientific community, that is, they were new discoveries and a new theory, Hubble's Law that described and explained the galaxies separating from each other at accelerating rates; when Edwin Hubble made a series of telescopic observations and discovered that the galaxies were separating at accelerating rates, the international scientific community still claimed that the galaxies were static in relation to each other, and some theoretical physicists claimed there was a “fifth force” that held the galaxies in relation to each other.

Alfred Louis Kroeber also studied cultural growth in his Configurations of Cultural Growth and other works; however, Louis Kroeber recognized that sometimes high-level innovations in cultural patterns jump, leap, or fly ahead of the established symbolic cultural patterns and technological growth of the generations of which the new or high-level innovations emerge.

It is many times commented that Charles Darwin's theory of evolution and the body of Darwinist theory more generally does not allow 'large mutations' or so-called 'macro mutations' across human individuals or individual organisms of other species, since the large mutations across individual organisms are not assimilable by the genetics of breeding populations; however, small or slight heritable variations across human individuals that result in a diversity of behavioral characteristics or branching patterns of behavioral characteristics across human individuals themselves, when expressed in culture and cultural patterns by human individuals and human social groups, like written languages (Latin, English, or other languages) or Arabic numerals, there may result in spectacular expressions of "progress" in behavioral patterns and cultural achievements in science, philosophy, religion, technology, music, and the arts. Prominent examples include the scientific revolution of Claudius Ptolemy, or the scientific revolutions of Copernicus, Galileo, or Newton, or the technological revolutions of Watt, Marconi, Edison, Ford, Bill Gates, or Steve Jobs, or the religious "revolutions" that established the major world religions, of Confucius, Buddha, Christ, or Muhammed. Important cultural achievements, or cultural "progress," or "revolutions," sometimes are not generational: Alfred Louis Kroeber comments that the Chinese language existed for thousands of years before Chinese scholars recognized, when in contact with and translating Buddhist texts from Sanskrit, that the Chinese language had tones; Wittgenstein, Noam Chomsky, and Jorge Luis Borges suggest that ideas about the nature of language remained largely unchanged since the work of St. Augustine; philosopher John Dewey comments that concepts of biological inheritance remained largely derivative of Aristotle's concept of 'pangenesis,' including the work of Darwin and Wallace, until Mendel's conception of particulate units of genetic inheritance; the particulate units of genetic inheritance that Mendel postulated to develop his simple predictive rules on the nature of genetic inheritance were not identified for nearly a century, by Watson and Crick in their model of the double-helical structure of the DNA; early physics retained Aristotle's theory of gravity until Galileo showed Aristotle's conception to be illogical and theory to be empirically wrong.

From Ogburn's perspective, scientific theory, scientific knowledge, and mathematics usually "lag" behind incessant or nearly incessant technological growth; however, sometimes, scientific discoveries or scientific theory jumps, leaps, or flies ahead of established knowledge and even contemporary technology.

Declaration

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