RESEARCH ARTICLE

The Meaning of 'Secular' as a Scientific Concept

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The meaning of 'secular' in the scientific use of 'secular trend', 'secular variation', and similar terms is a topic that merits historical investigation. The scientific meaning for 'secular' has an origin and independent role apart from both religion and secularization. Fields in the social sciences, life sciences, and natural sciences have been using the concepts of 'secular trend' and 'secular variation' for almost two centuries. The field of economics was the first among the social sciences, while epidemiology was the first in the life sciences. Both disciplines adapted the use of 'secular trend' and 'secular variation' from the earth sciences, which borrowed the idea of 'secular' from astronomy. Early astronomical texts first used 'secular' to describe 'secular inequalities' and 'secular variations' in long-term patterns to celestial motions. Astronomers had found *saeculum* to be a convenient Latin word from ancient Rome to refer to a century's duration. This article recounts the intellectual history of the scientific uses, which continue to lack a relationship with anything religious to the present day.

The Secular Meaning of 'Secular'

The concept of the secular does not have to mean not-religion or non-religion. The assumption that the 'secular' is only conceivable through some idea of 'religion' or the 'religious' – whether in static or dynamic tension – is demonstrably incorrect. The root meaning of 'secular' is entirely secular, by referring to the temporal and worldly, and this secular meaning of the term 'secular' had historical exemplifications, long before secularization or secularism's articulation. The term's original Latin usage, and early scientific meanings date back to the fifteenth century and are unrelated to religion. This article recounts the intellectual history of those scientific uses, which continue to lack a relationship with anything religious down to the present day.

Medieval Christian thinkers appropriated the term from the Latin of Rome, where the *saeculum* referred to human ages. According to the Oxford Classical Dictionary,

> In Roman conceptions of time, the *saeculum* became the longest fixed interval, calculated as a period of 100 or 110 years (as opposed to, e.g., a *lustrum* of only five years; cf. "census"). The term originally indicated a "generation" or "lifetime," but greater significance developed through its association with the Ludi Saeculares (Secular Games), which were performed to celebrate the advent of a new saeculum in Rome.[1]

The complex story of Christianity's appropriation of *saecularis* during its cultural monopoly over Europe will not

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be re-told here. It suffices to point out how 'secular' could serve as a contrasting concept precisely because the secular already had a prior independent basis. The Christian Church was socially inventive, but it did not inaugurate the wider world.

> The word secular refers simply to "the world" and has no immediately antireligious connotation. Indeed, in the history of the Christian church, some clergy, such as the local priest, were called secular because they served parishioners out in the world while others remained cloistered.[2]

The Oxford English Dictionary recognizes this etymology by noting the primary meaning of 'secular' as "temporal, worldly."

Secondary meanings for 'secular' proved useful for Christianity's comprehension of its relationships with non-Christian ideas and institutions. The term "secularism" as a civic and political idea is related to religion. That is why modern social theory expects, as Talal Asad does, that "The concept of 'the secular' today is part of a doctrine called secularism."[3] However, it is mistaken to assume, as Asad does, that "The concept of the secular cannot do without the idea of religion."[4] What sounds tautologous in one discipline, such as sociology or political theory, need not be axiomatic for another, such as intellectual history or history of science. The concept of the secular can do without either the idea of religion or secularism. As this article explains, many scientific fields apply the original concept of the secular without any idea of religion getting involved, and science did not craft its meaning of 'secular' in order to mark a contrast with religion.

Early sciences borrowed the Latin word *saeculum* and its meaning of a 'human age' and 'century' to indicate a long

duration of periodic time. In worldly time, notable events can be recorded and arranged, so broader patterns to orderly events can become amenable to empirical inquiries. Astronomy was the first empirical science to use the term because the courses of the stars, the sun, the moon, and the visible planets displayed regular paths upon careful observation. Only records spanning decades and centuries could reveal longer-term patterns – what were labelled as secular patterns by the sixteenth century – such as the recurrences of solar eclipses and the precession of the equinoxes. After astronomy, that meaning of 'secular' was borrowed by other sciences in the nineteenth and twentieth centuries. Scientific understandings of the 'secular' are not just conceivable, but visible and practical in today's world.

Encountering the Secular Today

Anyone who has perused textbooks of astronomy or geology can encounter the term 'secular trend'. The fields of geography, ecology, and climate science have been using it, and people well-read in public health and epidemiology see mentions of 'secular trend' on occasion as well. This term can also show up in demographics, economics, and political science. The term 'secular trend', along with related terms such as 'secular variation', evidently has a useful academic meaning.

One does not have to be an academic to encounter the concept of a 'secular' trend or variation. A headline from Britain's *Daily Mail* website in October 2017 read, "It's true! You really are more likely to lose your hair in summer and fall, finds 12-year study." Readers saw the following quotation from this study: "The results of this secular trend study suggest that hair loss in the population is significantly correlated with seasonality."[5] The idea of a secular trend can be occasionally encountered in such reports about new medical research. Other sciences are occasionally using 'secular'. Visitors to the Science Daily blog whose attention was caught in 2017 by the headline "Earth's Magnetic Field 'Simpler Than We Thought'" learned about "patterns in Earth's magnetic field that evolve on the order of 1,000 years," including the "paleomagnetic secular variation."[6]

Readers of a 2014 story at Science Daily with the headline "Last Decade's Slow-Down In Global Warming Enhanced By An Unusual Climate Anomaly" learned that a "hiatus in global warming ongoing since 2001 is due to a combination of a natural cooling phase, known as multidecadal variability (MDV) and a downturn of the secular warming trend."[7] Readers can also encounter the term 'secular' in business headlines. Talk of a "secular bull market" or a "secular bear market" is commonly heard from stock market prognosticators. A *Wall Street Journal* headline from May 2017 read: "'Secular stagnation' even truer today, Larry Summers says." This article quotes Summers, a Harvard economist and former Treasury secretary, pointing out evidence supporting his view, such as: "If you look at the real interest rate decade by decade, it's been going down for five decades."[8]

If the only familiar idea about the 'secular' is a contrast with 'religious', one might wonder when there was a religious stock market, or a religious trend to climate change. No such things ever existed, of course. That contrast meaning to 'secular' resides within the Christian context, set up for theological and ecclesiastical purposes.[9] There are other contexts where the meaning of 'secular' has nothing to do with religion. The natural sciences, the life sciences, and the social sciences used the concepts of secular trend and secular variation during the nineteenth and twentieth centuries, with some usage starting centuries earlier. Early scientists did not adopt 'secular' so they could describe the world differently from religion. The view that science is unreligious, or even anti-religious, is a controversy from a later era. Nor were early scientists consulting their Christian lexicons for the right ecclesiastical term. The actual explanation for the early scientific interest in the 'secular' is far simpler. In Latin, *saeculum* meant a lengthy duration of time: a very long lifetime or approximately a century. This temporal measure of a worldly duration is the basic meaning to 'secular'. The word drifted into the Romance languages as *secolo* in Italian and *siècle* in French. This temporal meaning is the root secular meaning of 'secular', and the sciences borrowed it to describe features of the world having a very long duration.

This article's sections chart the intellectual heritage of the 'secular' that is evident in various sciences, going back to its first usage by astronomy during the seventeenth century as 'secular inequality' or 'secular variation'. During the early nineteenth century, the term 'secular variation' was borrowed by geology and geography, then by epidemiology, and then followed by medicine by mid-century. During the mid-1800s, social statisticians increasingly focused on detectable long-term patterns in their tabular data too, so these terms 'secular variation' and 'secular trend' were next borrowed by political economy and sociology. The final sections describe how astronomers first came to use 'secular inequality' by applying the Latin word *saeculum* to label centuries of time in their tables of astronomical calculations.

Secular Trends in the Life Sciences

A short-term cycle, such as a seasonal cycle, can be tracked in populations over many years to reveal longer-term and more stable patterns. Academic writings in human biology and public health use the term 'secular trend' to refer to such long-term patterns. This example comes from an epidemiology textbook: "The incidence of many infectious diseases varies over time. A *secular trend* is a change in the incidence of disease over an extended period."[10] An author of a work in medical anthropology explains the meaning of 'secular' for the discipline of biology:

> A secular trend is a gradual, unidirectional change in a characteristic over time. The word "secular" is related to the Latin word for "century" (saeculum); therefore a secular trend is one that takes place over one hundred years or over two or three generations. For example, ages at menarche have become earlier over time (Eveleth and Tanner) and height has increased over time (Bogin).[11]

Medical textbooks have applied 'secular' during the twentieth century to characterize long-term trends detected in the accumulated observations of health and disease in human populations. Epidemiology was the area of medicine to first describe 'secular' phenomena of disease. Here is an example from the 1930s, in C. O. Stallybrass's *The Principles of Epidemiology and the Process of Infection*: "The secular variations [of disease] … take place during the course of several generations of men"[12] In another article on "Epidemiology" in *Green's Encyclopedia and Dictionary of Medicine and Surgery* (1907) gave this definition:

> Some of the more important epidemic phenomena fall under the following heads:– 1. Secular mutations occurring during the course of centuries. 2. Multiannual mutations, to use the phrase of Ransome, or fluctuations in prevalence and virulence extending over periods of from ten to fifty years. Epidemic waves or explosions recurring at more or less regular intervals of a few years. 4. Seasonal fluctuations. 5. Oscillations at irregular intervals measured by days or weeks.[13]

The most widely consulted medical text of the late 1800s, Richard Quain's *A Dictionary of Medicine* (1882) contained an article on "Periodicity in Disease" which distinguished the seasonal changes of a disease's prevalence from the longer-term secular progressions of wide-spread epidemics. The physician who wrote this article, John Netten Radcliffe, was a London health inspector and President of the Epidemiological Society during 1875–77, and he authored several reports on the spread of epidemics. In this dictionary article, Radcliffe recounts the studies of medical authorities who speculated that an epidemic's secular course, having no local explanation, is due to a hidden connection with terrestrial climate patterns, repeating meteorological phenomena, or astronomical cycles. After citing a long list of pandemics in recorded history, Radcliffe proposes that "In these phenomena we have evidence of secular pathological changes, to which a clue is sought in studying their relation with secular meteorological and telluric changes."[14]

Radcliffe particularly appealed to the work of Thomas Laycock in England and Charles Anglada in France. Laycock's articles in *The London Lancet* during 1842–44 on "Periodicity in the Phenomena of Life" inspired this summarization from Radcliffe:

> He set forth data which suggested that those changes, as well as the periodical changes observed in disease, had definite relations to the position of the earth with reference to the sun, and to the position of the sun among the spheres; also to the periodical fluctuations occurring in atmospherical temperature, pressure, and magnetism; and in the magnetism of the earth, whether diurnal, seasonal, or secular.[15]

Laycock prophesized the inauguration of a medical "proleptics" capable of forecasting the courses of diseases and the arrival of epidemics. Although Laycock did not use the term 'secular' himself, he did appeal to an analogy with terrestrial and astronomical changes, and he expected that correlations between disease patterns with those physical patterns would reveal causal relations.

> Proleptics is not limited to periods of any particular duration; it applies itself alike to periods of hours or of thousands of years. It is within its province to investigate the changes induced in the earth and in society at the completion of grand cycles, as well as the changes induced during a single revolution of the earth on its axis or round the sun. It concerns itself with all astronomical phenomena, because they are eminently periodic; it traces the laws of recurrence of cosmic and telluric changes, with special reference to the influence of those changes on man, either as an individual or in society.[16]

Radcliffe also highlighted the concept of 'secular evolution' from Charles Anglada, a professor of pathology at the University of Montpellier in southern France. His *Étude sur les maladies éteintes et les maladies nouvelles, pour servir a l'histoire des évolutions séculaires de la pathologie.*was published in 1869. Biological evolution in Darwin's sense was not on Anglada's mind. However, Anglada did ponder the multi-year course of epidemics from generation and transmission to extinction, and he explicitly associated the medical study of epidemics with the astronomical study of celestial phenomena.[17]

Radcliffe would have also seen in the pages of the *London Lancet* additional mentions of secular change by physicians exploring the physical cycles of life. For example, Dr. Samuel Haughton's 1868 address to the British Medical Association begins with this statement:

> Man, like other animals, is born, grows, comes to maturity, reproduces his like, and dies; passing in his lifetime through a cycle of changes that may be compared to a *secular* variation, by a metaphor borrowed from the science of astronomy; while, in his daily life, he passes through a smaller cycle of changes that may be called *periodic*.[18]

Since Haughton had already published textbooks of natural science, such as his *Manual of Geology* which mentions the moon's mean secular motion and the earth's slow secular cooling,[19] his metaphorical step from an astronomical and geological context over to a biological context was straightforward.

The use of 'secular' in a medical context is very rare or non-existent prior to the 1860s, as far as book searches have been able to reveal. Connecting the courses of disease with variations in earthly or celestial phenomena is much older. The idea that epidemics are correlated with terrestrial conditions, and possibly meteorological or astronomical events, was familiar to the medical profession during much of the nineteenth century, until the germ theory of disease transmission was accepted.[20] The term 'secular' had evidently made the leap from texts of natural science to medical texts by the 1860s.

Physicians familiarizing themselves with the natural sciences had at hand the finest survey: Alexander von Humboldt's *Kosmos: A Sketch of a Physical Description of the Universe*, published in multiple volumes starting in 1845.[21] These enormously popular volumes, which were promptly translated into English and other European languages, use the idea of 'secular' (*seculären* in German) for very slow and gradual changes. *Kosmos* discusses the secular cooling of the earth, the secular variations of the quantity of solar heat received by the earth, the secular movement of isogonial lines of the earth's magnetism, the secular rise of an area of land up from sea-level, the secular inequalities of the moon's orbit, the secular changes in the orbits of Jupiter and Saturn, and the secular retrogressions of the apsides of the asteroids Ceres and Pallas.

After the next section on the social sciences, we shall return to the natural sciences of the mid-1800s.

Secular Trends in the Social Sciences

Not surprisingly, texts in public policy and political science define the term 'secular trend' in the same way. William Dunn's *Public Policy Analysis*, now in its sixth edition, provides this definition:

> Classical time-series analysis may be used for extrapolative forecasts. Classical time-series analysis divides time series into four components: secular trend, seasonal variation, cyclical fluctuation, and irregular movement. A *secular trend* is a smooth long-term growth or decline in a time series.[22]

A widely used textbook of political science from the 1960s offered the same conception of a secular trend:

> The secular trend can be defined as the long-term movement in a series of numbers. Long-term changes in the size of the population — of the country, cities, a city, and so on — per capita income, votes for the Democratic or Republican party, the amount of money spent on campaigns for national, state, or local office – are all examples of data that may have a long-term secular trend.[23]

The field of economics distinguishes a secular trend from a cyclical trend in the same way:

> A secular trend is the long-run pattern of increase or decrease in a series of economic data. Cyclical fluctuation describes the rhythmic variation in economic series that is due to a pattern of expansion or contraction in the overall economy.[24]

This shared definition for 'secular trend' is no coincidence; political science and economics have a common academic heritage. For example, the term 'secular stagnation' was due to economist Alvin Hansen, whose analyses were politically relevant during the Great Depression. He explained his concern for secular stagnation, in addition to worrisome business cycles, in this way:

Not until the problem of full employment of our productive resources from the long-run, secular standpoint was upon us, were we compelled to give serious consideration to those factors and forces in our economy which tend to make business recoveries weak and anaemic and which tend to prolong and deepen the course of depressions. This is the essence of secular stagnation – sick recoveries which die in their infancy and depressions which feed on themselves and leave a hard and seemingly immovable core of unemployment.[25]

In Hansen's assessment, short-term business swings are manifest cycles of economic activity, but long-term secular trends also deserve attention from the political arena.

Sociology was also at the root of this common understanding of a 'secular' trend. A decade earlier, sociologist Stuart A. Rice, who was instrumental to the U.S. Census Bureau and the Office of Statistical Standards in the Bureau of the Budget, introduced quantitative methods into political science. His widely influential *Quantitative Methods in Politics* distinguished secular trends from other features of time series data in this manner:

> Variations in time in economic data are usually credited to one or another of four types of factors. There are, first, those factors whose combined influence operates with a degree of constancy, or a degree of constant change, over a relatively long period of years. The effects of these factors, when isolated, give rise to what is termed "secular trend." There are, next, those which result in cycles of several years' duration, giving rise, when isolated and plotted, to a more or less wave-like curve about the line of trend. Third, there are frequently seasonal influences, causing a somewhat rhythmic pulse within the yearly period. Lastly, there are fortuitous factors like the World War, unassociated with the trend, the cycle, or with seasonality.[26]

The isolation and verification of long-term trends from shorter-term events was a much-debated statistical problem for the field of political economy, as it was known in academia since the 1800s. America's prominent economic theorist of the early twentieth century, John Rogers Commons, published an influential paper about this theoretical difficulty in "Secular Trends and Business Cycles: A Classification of Theories" (1922), recounting views on detecting long-term trends advanced by Malthus, Ricardo, and Marx, among others.[27] While Commons was not a exponent of John Maynard Keynes's work in political economy to the degree exhibited by Hansen, they both knew well the landmark text by Keynes, *The Scope and Method of Political Economy* (1891). In that treatise, Keynes used his mathematical expertise to explain how a periodic fluctuation can swing across an average, while that average itself is probably changing over a longer term of many periods.

> In dealing, for instance, with the statistics of some phenomenon over a term of years, we may seek to establish a periodicity in the movements towards

and away from the average; but the average, if taken for successive periods of years, may itself be subject to progressive variations, and unless these are correctly calculated and due allowance made for them, our conclusions may be seriously vitiated. … On the other hand, if we are studying the secular movements, it is equally necessary to have analysed the periodic variations.[28]

But behind Keynes stood the towering figure of that English polymath, William Stanley Jevons. Economists of both Commons' and Keynes's generations studied the second edition (1879) of Jevons's *The Theory of Political Economy* and the posthumous volume (1884) of Jevon's collected writings titled *Investigations in Currency and Finance*. Other works by Jevons on logic, statistics, geometry, calculus, the natural sciences, and scientific methods prepared him for understanding the fuller implications of tracking economic activity with mathematical tools.

H. S. Foxwell, successor to Jevons in the chair of political economy at University College London, edited the *Investigations* and pointed out the scientific significance of Jevons's theories in this volume's Introduction. Foxwell emphasized how Jevons tried to apply methods of inductive investigation from the physical sciences into the field of economics. Among those methods is the calculation of periodic variations (to commodities, or currencies, for example), which Jevons explained in *The Principles of Science* (1874). That book distinguishes 'periodic' and 'secular' variations of a measured phenomenon, such as astronomical observations of the moon or a planet: "the variation is called secular, because it proceeds during ages in a similar manner, and suffers no περίοδος or going round."[29] Jevons did recognize that a secular change of long duration may eventually return to some earlier state, if that fate can be predicted from enough accumulated evidence. Jevons cites Pierre-Simon Laplace's calculations that the bodies of the planetary system will undergo their periodic changes over enough time so that their orbits remain within stable boundaries. The destiny of a secular variation is usually not determinable, so Jevons adds, "Any change which does not present the appearance of a periodic character will be empirically regarded as a secular change for the present, so that there will be an abundant supply of non-periodic variations."[30]

Aside from Jevons's overview of periodic and secular variations in *The Principles of Science*, the word 'secular' does not appear in his economic writings, where only the distinction between periodic and non-periodic variations is mentioned. However, Foxwell guaranteed that students of Jevons could not overlook the term 'secular variation' by drawing the reader's attention to Jevons's path-breaking analyses of seasonal, decennial, and secular variations to the currency supply, and especially to "the great secular variation, the change in the value of money."[31] Foxwell cemented the importance of calculating secular variations by crediting Antoine-Augustin Cournot with establishing that illuminating analogy between economic fluctuations and astronomical motions. He even quoted a passage from Cournot's *Principes de la Théorie des Richesses*, published in 1863, which explicitly makes that comparison by referring to "les variations séculaires" of celestial bodies.[32] In fact, Cournot had already written about secular variations in an economic context in his earlier 1838 treatise *Recherches sur les principes mathématiques de la théorie des richesses*.[33] With doctoral degrees in mathematics and astronomy, Cournot understood the basis to this constructive analogy between astronomy and economics.

Foxwell does not credit Cournot with conveying any astronomical analogies into Jevons's economics. Jevons first encountered Cournot's work in 1873, well after Jevons had proposed his own plan to study economics with methods essential to the physical sciences.[34] In his initial mathematization of economics, "On the Study of Periodic Commercial Fluctuations" (1862), Jevons had written:

> It seems necessary, then, that all commercial fluctuations should be investigated according to the same scientific methods with which we are familiar in other complicated sciences, such especially as meteorology and terrestrial magnetism. Every kind of periodic fluctuation, whether daily, weekly, monthly, quarterly, or yearly, must be detected and exhibited, not only as a subject of study in itself, but because we must ascertain and eliminate such periodic variations before we can correctly exhibit those which are irregular or non-periodic, and probably of more interest and importance.[35]

Cournot's work was largely unknown until the 1870s, and he was not the only social theorist besides Jevons to think about economic factors in terms of short-term vs. long-term change. For example, Henry Sidgwick's *The Principles of Political Economy* (1883) points out the difference between short-term changes and longer-term "secular variations" to commodity production.[36] Sidgwick expresses his many debts to Jevons's work, so his chosen terminology may trace back to Jevons.

Another theorist using the term 'secular' in a scientific manner also arrived in 1883 from the neighboring discipline of sociology. Lester Frank Ward gave his book *Dynamic Sociology* the revealing subtitle: *Applied Social Science, as based upon Statical Sociology and the Less Complex Sciences*. The natural sciences of astronomy, physics, geology, chemistry, and biology are his chosen exemplars, and Ward's frequent use of 'secular' refers to very gradual and slow-working processes studied by those sciences.[37] However, Ward undertakes no specifically economic theorizing.

Besides Cournot, only two notable social scientists who pre-dated Jevons explicitly compared the search for long-term variations in economics with the study of long-term variations observed in astronomical phenomena: Henry Dunning Macleod and Dionysius Lardner. Macleod's *The Elements of Political Economy* (1858) was well-known to Jevons, whose own work on political economy took favorable notice of Macleod's attempt to apply mathematical formulas. In this book Macleod had written,

> Just as in astronomy the changes of the position of the heavenly bodies, which are at a very great

distance from us, are barely perceptible after long continued observations, and they may be used to serve as standard to note the changes in position of those which are comparatively speaking close to us—such as the moon and planets. And the former are termed "fixed", though in reality it is known that they are all in rapid motion. So for short periods, the value of money may be considered as fixed, without material risk of error; and changes in the value of money may be compared to the secular variations of the heavenly bodies.[38]

Jevons did not use the term "secular variation" himself, as we have already noted. Jevons did make use of Macleod's inquiries into cyclical commercial crises in order to pursue his own hypothesis that the rhythm of economic downturns are correlated with influences from meteorological and astronomical events, such as the cycles of sun spots.[39]

As for Lardner, his *Railway Economy* (1850) refers to slow secular change only once, but it similarly evokes astronomical methods in the course of describing railway structures:

> That wear and tear which, being due to the slow operation of time acting upon the more solid structures, produces an effect altogether insensible when observed through short periods, but which, after a long interval of time, such, for example, as centuries, must necessitate the reconstruction of some or all even of the most solid structures. These changes may not unaptly be assimilated to the periodical and secular inequalities which take place in the movements of the great bodies of the universe. The operation of time upon the more massive works of art upon the railway, such as the bridges, tunnels, viaducts, & c., afford examples of what may be called the secular wear and tear. The more rapid and visible deterioration, which is made good by repairs or reconstruction effected at shorter intervals, is analogous to the periodic inequalities.[40]

Lardner's book is cited in the bibliography to Jevons's *The Theory of Political Economy*, but that reference did not do full justice to the extent of Lardner's influence. The Preface to the second edition of Jevons's *Theory of Political Economy* is the place where Jevons expresses his large debt to Lardner's *Railway Economy*. In the words of a later editor of Jevons's papers, Rosamond Könekamp, it was Lardner who "first gave him the idea of investigating economics mathematically."[41]

Besides Lardner, Macleod, and then Jevons, no pioneer of economics in the English language was appealing to astronomical ideas for assistance with the investigation of regular patterns, short-term and long-term, calculable from economic data. Neither William Whewell nor John Stuart Mill, for example, who were both familiar with astronomy's study of periodic and secular variation, transferred that distinction into economics. In the French language, two economists who introduced mathematical

analyses into their theories used the term 'variations séculaires': Augustin Cournot in *Recherches sur les principes mathématiques de la théorie des richesses* (1838) and *Principes de la Théorie des Richesses* (1863), and Léon Walras in *Éléments d'économie politique pure, ou, Théorie de la Richesse Sociale.*[42] With the exception of Lardner, what distinguishes the four theorists who investigated short-term and long-term economic changes using mathematics (Cournot, Macleod, Walras, Jevons) was their abiding interest in tracking changes in the real value of precious metals as both commodity and currency over the course of several decades. Walras and Jevons acknowledged the acquaintance with Cournot's work, while Macleod included a reference to Cournot's *Recherches* in his *A Dictionary of Political Economy* (1863). It is plausible that Lardner could independently arrive at the mathematical analogy between astronomy and economics, although he did have ample opportunity to read Cournot by the 1850s.[43] Lardner had already published several textbooks about mathematics and science, such as his *Hand-book of Natural Philosophy and Astronomy* (1853) which includes explanations of periodic and secular variations to lunar, solar, and planetary motions.

Having proposed that the transferal of the idea of a long-term 'secular variation' from astronomy to economics was accomplished in writings by Cournot and Lardner, which Jevons consulted, it should be said that the credit for securely embedding that concept within economic theory goes to Jevons's editor, H. S. Foxwell. Practically nothing about the economic views pursued by Cournot, Lardner, or Macleod survived the critical eyes of Jevons and the marginal utility school of economics.[44]

All the same, Cournot was the first among political economists to distinguish long-term secular variations from short-term periodic variations in *Recherches sur les principes mathématiques de la théorie des richesses*. The translation of the key paragraph reads,

> … articles such as wheat, which form the basis of the food supply, are subject to violent disturbances; but, if a sufficient period is considered, these disturbances balance each other, and the average value approaches fixed conditions, perhaps even more closely than the monetary metals. This will not make it impossible for the value so determined to vary, nor prevent it from actually experiencing absolute variations on a still greater scale of time. Here, as in astronomy, it is necessary to recognize *secular* variations, which are independent of *periodic* variations.[45]

There can be no doubt that Cournot's understanding of 'secular variation' came from his doctoral study of his fellow Frenchman, the greatest astronomer of the age, Pierre Laplace. Laplace greatly advanced the mathematical treatment of celestial mechanics after Isaac Newton, including explanations for puzzling deviations and perturbations of lunar, solar, and planetary motions. Those motions exhibited what astronomers had called 'secular inequalities' since Kepler's time. But our story must next discuss the other natural sciences.

Secular Trends in the Natural Sciences

The earth sciences, such as physical geography, geology, oceanography, meteorology, and climatology, inherited their usage of 'secular', in such terms as 'secular trend' and 'secular variation', from the field of astronomy.

Here is a recent example of a mention of 'secular trend' from a textbook of hydrology:

> A secular trend is a tendency to increase or decrease continuously for an extended period of time in a systematic manner. The trend can be linear or non-linear. If urbanization of a watershed occurs over an extended period, the progressive increase in peak discharge characteristics may be viewed as a secular trend. The trend can begin slowly and accelerate upward as urban land development increases with time. The secular trend can occur throughout or only part of the period of record.[46]

The McGraw-Hill textbook *Introduction to Geophysics* (1959) explains the kinds of changes to the earth's magnetic field: "The variations are of three types: (1) a secular variation, (2) short-term regular periodic variations, and (3) irregular transient fluctuations."[47] Geologist John Milne, inventor of the modern seismograph, explains the connection between rising land and earthquakes in his landmark work *Seismology* (1898): "wherever we find in progress those secular movements which result in the building up of countries or mountain ranges, there we should expect also to find a pronounced seismic activity."[48]

Geology began applying the term 'secular' for slow changes to the earth during the early 1800s, and it was fairly common by the mid-1800s. For example, William Thomson (later Lord Kelvin) published his controversial paper "On the Secular Cooling of the Earth" in 1863.[49] Although scientifically estimating the earth's true age got entangled with post-Darwinian debates with Biblical creationism, that geological question had nothing to do with religion. The slow "secular" cooling of the earth's inner heat was a purely scientific issue long before Darwin. Like Lord Kelvin, mid-nineteenth century naturalists with expertise in physical geography and geology displayed no lack of familiarity with astronomical principles. *Kosmos* by Humboldt is one illustration; *Principles of Geology* by Charles Lyell is another.

Lyell makes that same distinction between very slow secular changes and faster periodic changes, in the context of considering the potential effects of variations of the sun's light on "secular changes" to terrestrial climates, and the hypothesis that the earth has been undergoing a "secular decrease of internal heat" since its formation.[50] In fact, the first edition of Lyell's *Principles of Geology* in 1830 phrases the question of the earth's cooling interior as the inquiry into "whether it be subject to secular variations."[51] This is a very early application, perhaps the first in the English language, of the astronomical idea of 'secular variation' to a geological matter. Before Kelvin and Lyell, Joseph Fourier had pioneered formulas for calculating the "refroidissement séculaire" of the rate of the earth's slow cooling in a paper published in 1820.[52] Fourier had succeeded Joseph-Louis Lagrange as a professor of mathematics and mechanics at the École Polytechnique in Paris. Having been the student of both Lagrange and Laplace, Fourier was intimately familiar with astronomy's problem of 'secular inequalities', which had been thoroughly investigated by his teachers.

Laplace's monumental *Traité de Mécanique Céleste* (published in five volumes from 1798 to 1825) includes calculations and explanations for the "inégalités périodiques et séculaires" of the bodies of the solar system.[53] England's brilliant mathematician, Mary Somerville, published a precise yet readable rendition of *Mécanique Céleste* as *The Mechanism of the Heavens* in 1831. In her words,

> The planets are subject to disturbances of two distinct kinds, both resulting from the constant operation of their reciprocal attraction, one kind depending upon their positions with regard to each other … such changes, being accomplished in short periods, some in a few months, others in years, or in hundreds of years, are denominated Periodic Inequalities. The inequalities of the other kind, though occasioned likewise by the disturbing energy of the planets, are entirely independent of their relative positions; they depend on the relative positions of the orbits alone, whose forms and places in space are altered by very minute quantities in immense periods of time, and are therefore called Secular Inequalities.[54]

Somerville's book was initially intended for inclusion in the Library of Useful Knowledge series of books about science, but its ample length required separate publication. The titles in this series, due to their readability and low price, became some of the best-selling texts on science during that era. The third volume of *Natural Philosophy* in the Library of Useful Knowledge, published in 1834, covered astronomy, geography, and navigation with chapters from multiple authors.[55] By coincidence, Somerville's next book also appeared in 1834. *On the Connexion of the Physical Sciences* covered astronomy, geology, and geography along with physics, and it was an even greater publishing success.[56] Both books are replete with the term 'secular' – they talk about secular equations, secular inequalities, and secular variations, along with secular increases, secular accelerations, secular disturbances, and secular diminutions, which are evident in both celestial and terrestrial phenomena. We may presume that from that date of 1834, the scientific use of 'secular' to indicate slow measureable change is firmly established in the English language.

Before 1820, the only science to rely on the idea of 'secular' change was astronomy. A widely-used textbook dating from the 1830s by John Grummere explains why a mathematical equation giving the formula for locating the sun's position over years and centuries won't be precisely correct, and that inevitable amount of error is an "inequality" that slowly changes over centuries.

> By a comparison of observations made at distant periods, it has been discovered that the equation of

the sun's centre, and consequently the eccentricity of the orbit, are at the present period continually diminishing. The rate of diminution in the greatest equation is about 18″ in a century. It follows, therefore, that the equation of the centre, as computed for a given time, will not be accurately true for a different time. It will, however, err but little for a few years, before and after the time, for which it is computed. A complete table of the equation of the sun's centre, has a column containing the variation of the equation in a century, called the Secular variation, by means of which the correct equation may be obtained for different periods.[57]

Astronomical tables published during the eighteenth and early nineteenth centuries often include that additional column, to provide a correcting amount for each decade or century so that an equation for the position of the moon, the sun, or a planet can yield a more accurate result. Almanacs for practical astronomy, such as nautical almanacs, provide tabular information for a few years at most, while advanced astronomy treatises may offer tables covering centuries into the past and forward into the future, requiring an additional column for the secular variation. Calculating the precession of the equinoxes, the occurrence of a solar eclipse, or the conjunctions of Jupiter and Saturn, as primary examples, require taking secular inequalities for each event into account. By the mid-1800s, astronomers had closely calculated the rates to secular variations and accelerations for many celestial motions, so large tables with columns for many years and centuries were replaced by small tabular figures and a few formulas. For example, Simon Newcomb's 1895 supplemental volume to the American Ephemeris and Nautical Almanac describes the rate of the ecliptic's precession with a table that only lists the variations to longitudes and right ascensions for the years 1350, 1600, 1850, 2100, and 2350, followed by specific variations to use annually and centennially.[58]

Before the secular variations to ecliptic, lunar, solar, and planetary motions were well understood and closely calculated, astronomers could only compile large tables to provide figures for the secular variations corresponding with past and future centuries. The slow acceleration of the Moon's motion was announced by Edmond Halley, but he did not attain a satisfactory understanding of this phenomenon. His *Tabulae Astronomicae* (1749) does provide tables for corrections to lunar and solar motions. For example, the table for "Motus anomalie mediae et apogei solis" lists the needed corrections for the Sun's position by century, starting with the year 100 at the top, continuing through 1600, 1700, 1800, and so on, until reaching the year 3100 at the bottom.[59] His tables for the positions of Jupiter and Saturn include corrections across the centuries from 100 to 3100 AD, labeled as 'Aequatio Secularis' (secular equation). Another mathematician and astronomer, Leonhard Euler, published tables for the secular equations of the Sun and Moon in volume one of his *Opuscula varii argumenti* (1746). Subsequent astronomers followed these two precedents.[60]

C. M. Linton explains the origin of the term 'equation', inherited from Ptolemy, in this context of early astronomy:

> In general, the term 'equation' is used to refer to any angle that must be added or subtracted from a mean motion in order to account for a particular geometrical feature. This is Ptolemy's style throughout – first the mean motions are described, and then the various small corrections, the equations, are calculated. In the case of the Sun, there was one such equation, but for the Moon and the planets there were more. Ptolemy's quantitative solar theory was used not only to determine the position of the Sun but was also an essential part of his theory for the other planets.[61]

When early astronomers included tables for variations to the mean motion of the Sun or the Moon that occur over centuries, 'secularis' means 'by century', so that the amount (the inequality) of a secular variation across each century can be indicated by its secular equation. Astronomy's use of the term 'variation' goes back to Tycho Brahe, as Linton recounts:

> In a series of observations in 1594, Tycho discovered the first wholly new astronomical phenomenon since Ptolemy's time, and one that reduced the error from existing theories of the longitude of the Moon by almost 75 per cent. He observed that the Moon sped up as it approached the syzygies and slowed down near the quadratures. This phenomenon, which shows up as a displacement of about 40′ from the position at the octants predicted by previous theories, has ever since been known by the name Tycho gave to it: the 'variation'.[62]

Johannes Kepler published Brahe's accumulated observations in the *Rudolphine Tables* (1627). In its Preface, Kepler remarked that a comparison with older observations by Regiomontanus and Walther reveal the need for an additional "æquationibus secularibus" – a secular equation – because the motions of the Sun and the Moon "have rather slight physical increases and decreases in an irregular way".[63] Kepler's superior formulas for elliptical orbits around the Sun allowed him to calculate positions for the Sun, Moon, and planets many centuries into the past and the future. His tables placed centuries in the first column on the left, beginning at the top with the year 4000 BC and ending at the bottom with 2100 AD.

Kepler was the editor of Brahe's *Astronomiae Instauratae Progymnasmata* (1602), which used a tabular labeling of successive centuries as 'Seculorum', most conspicuously in a table comparing calculations for the Sun's position in 1500, 1600, and 1700.[64] Earlier astronomical tables did not use the label "seculorum" in their tables, but the left column for successive centuries is used. A prominent example is the Prutenic Tables by Erasmus Reinhold (1551), which includes tables for the precession of the equinoxes that uses a left column for many centuries from 20 AD down to 5000 AD.[65]

This examination of the history of astronomy finds that the meaning of 'secular' in terms such as 'secular inequality' and 'secular variation' originated in sixteenth and seventeenth century astronomical tables presenting calculations of celestial motions century by century from the past into the future. As improved tables began to include information for slight century-by-century variations to lunar, solar, and planetary motions, the association of 'secular' with very slow changes over long periods of time was scientifically established.

Conclusion

The emergence of the empirical sciences was the setting where the original and primary meaning of 'secular' as "temporal and worldly" was borrowed and applied, apart from conceptual relations with anything religious. This secular meaning of 'secular' may be uninteresting to some disciplines, such as theology, religious studies, or sociology. For intellectual history and history of science, that core meaning of 'secular' has an origin and independence apart from both religious and secularism trends in the civic realm. Many disciples in the social sciences, the life sciences, and the natural sciences, indebted to astronomy, earth science, and economics, have long been using 'secular' with its primary meaning.

Notes

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Competing Interests