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# Moral Sentiments and Climate Change

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## 1 Knowledge of Science and Society

### 1.1 Moral Sentiments

There have been speculations that it is no accident that the most important cosmologist after Ptolemy was Nicolaus Copernicus (1473 – 1543), born only a decade before Martin Luther. Both attacked orthodoxy in different ways.[1] Copernicus formulated a scientifically based heliocentric cosmology that displaced the Earth from the center of the universe. His book, *De revolutionibus orbium coelestium* (*On the Revolutions of the Celestial Spheres*, 1543), is often regarded as the starting point of the Scientific Revolution. Moreover, in 1526 Copernicus also wrote a study on the value of money, *Monetae cudendae ratio*. In it Copernicus formulated an early version of the theory, now called "Gresham's Law," that "bad" (debased) coinage drives "good" (non-debased) coinage out of circulation,

Margolis (2002) noted that something very significant occurred in the years after Copernicus. His ideas influenced many scholars: the natural philosopher, William Gilbert, who wrote on magnetism in *De Magnete* (1601); the physicist, mathematician, astronomer, and philosopher, Galileo Galilei (1564 – 1642); the mathematician and astronomer, Johannes Kepler (1571 –1630).

*Philosophiæ Naturalis Principia Mathematica* (1687), by the physicist, mathematician, astronomer and natural philosopher, Isaac Newton (1642 – 1726) is considered to be the most influential book in the history of science.[2] Margolis (2002) argues that, from about 1600, scholars learnt to look at scientific and social problems from different angles, and that within the next two hundred years this habit of mind became quite common, and was, in fact, the reason why the technological/ industrial revolution gathered apace in the eighteenth and nineteenth centuries.

[1] Weber (1904) speculated that there was a connection between the values of Protestantism and Capitalism. It may be that there are connections between the preference for scientific explanation and protestant belief about the relationship between God and humankind.

[2] See Feingold (2004).

After Newton, a few scholars realized that the universe exhibits laws that can be precisely written down in mathematical form. Moreover, we have, for some mysterious reason, the capacity to conceive of exactly those mathematical forms that do indeed govern reality. We believe that this mysterious connection between mind and reality was the basis for Newton's philosophy. While celestial mechanics had been understood by Ptolemy to be the domain most readily governed by these forms, Newton's work suggested that *all* reality was governed by mathematics.

We shall call the underlying hypothesis entertained by these scholars *the universality of mathematics.* Major universal mathematicians include the Scot, James Maxwell (1831–1879), the Frenchman, Henri Poincaré (1854–1912), the German, Albert Einstein (1879–1955), and the Englishman, Stephen Hawking (born 1942).[3] Hawking and Mlodonow (2010) argue for this universal principle, citing its origins in Pythagoras (580 BCE to 490 BCE), Euclid (383 -323 BCE and Archimedes (287-212 BCE), and the recent developments in mathematical physics and cosmology. They present a strong form of this principle, called *model-dependent realism*, arguing that it is *only* through a mathematical model that we can properly perceive reality.

Without the application of this universal mathematics, our society would be quite different and much poorer. Jardine (1999,2008) discusses the scientific innovations by Hooke and Huygens in the period round the glorious revolution, while Appleby (2010) discusses the technological changes wrought by Arkwright, Hargreaves, and Crompton soon after. There is still controversy over whether the rapid technological and economic transformations that we experience today are the consequence of the development of science itself, or the result of the institutional changes in the political economy that started in Great Britain in the 1600's.[4] Ferris (2010) argues that the political and economic innovations of the time were linked to these developments in mathematics and science.

The influence of Newton can perhaps be detected in the work of the philosopher, mathematician, and political scientist, Marie Jean Antoine Nicolas de Caritat, Marquis de Condorcet (1743 – 1794), known as Nicolas de Condorcet. His work in formal social choice theory (Condorcet ([1785],1994) was discussed in Schofield (2006) in connection with the arguments about democracy by Madison and Jefferson. This work also discussed the influence of the work on Moral Sentiment by the Scottish Enlightenment writers, Francis Hutcheson (1694–1746), David Hume (1711–1776), Adam Smith (1723–1790) and Adam Ferguson (1723–1816).

Between Copernicus and Newton, the writings of Thomas Hobbes (1588 – 1679), René Descartes (1596– 1650), John Locke (1632– 1704), Baruch Spinoza (1632– 1677), and Gottfied Liebnitz (1646– 1716) laid down foundations for the modern search for rationality in life.[5] Hobbes was more clearly influenced by the

[3] Hawking (1988) writes of being able to read the "Mind of God."

[4] See for example, Landes (1998) and Warsh (2006).

[5] For Hobbes, see Rogow (1986). For Descartes, see Gaukroger (1995). For Spinoza and Liebnitz see Stewart (2006) and Goldstein (2006).

scientific method, particularly that of Galileo, while Descartes, Locke, Spinoza, and Liebniz were all concerned in one way or another with the imperishability of the soul.[6] Liebniz in particular was concerned with an

> [E]xplanation of the relation between the soul and the body, a matter which has been regarded as inexplicable or else as miraculous.

Without the idea of a soul it would seem difficult to form a general scheme of ethics.[7] Indeed, the progress of science and the increasing secularization of society over the last century led Ferguson (2002) to note that

> [l]oss of faith in [the British Empire] often went hand in hand with loss of faith in God.

## 1.2 Beliefs

In the 1920's and 1930's, after World War I and the devastation wrought by the application of science and technology, a general fear become prominent that civilization would fall, just as the Ottoman, Russian and Habsburg empires had fallen, soon to be followed by the British Empire.[8] These fears were exemplified first by Spengler's *Decline of the West* (1918, 1922) and later by Toynbee's *Study of History* (1934).

Ferguson (2006) quotes Spengler to the effect that

> The masses will accept with resignation the victory of the Caesars.

Mead (2007) suggests, in contrast, that "it is to a dynamic religion rather than secularization that we must look for explanations of the Anglophone ascendency [of the American empires]."[9]

Indeed, much recent work substantiates the ideas of the Scottish moral philosophers, and the later suggestions of Darwin (1871), proposing that we all have an innate sense of moral values. Ober and Macedo (2006) suggest that moral goodness is something real, and does not need to be based on the notion of a trancendent soul.[10]

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[6] It is of interest that the English word "soul" derives from Old English *sáwol* (first used in the 8th century poem, *Beowulf*.

[7] Hawking and Mlodinow (2010) assert that God did not create the Universe, perhaps implying that the soul does not exist. However they do say that they understand Isaac Newton's belief that God did "create" and "conserve" order in the universe. See other books by Dawkins (2008) and Hitchens (2007) on the same theme, as well as Wright (2009) on the evolution of the notion of God.

[8] See Lieven (2002) for a brief history of these empires and Overy (2009) for the fears about collapse in the interwar years in Britain.

[9] A recent Gallup poll found that 70% of Americans regarded religion is an important part of their daily lives, compared with 27% of British.

[10] See also Wright (2009).

The last twenty years has seen a growing literature on a game theoretic analysis of the evolution of social norms to maintain cooperation in prisoners' dilemma like situations. Gintis (2000, 2003), for example, provides evolutionary models of the cooperation through strong reciprocity and internalization of social norms.[11] The anthropological literature provides much evidence that, from about 500KYBP years ago, the ancestors of *homo sapiens* engaged in cooperative behavior, particularly in hunting and caring for offspring and the elderly.[12] On this basis we can infer that we probably do have very deeply ingrained normative mechanisms that were crucial, far back in time, for the maintenance of cooperation, and the fitness and thus survival of early hominids.[13] These normative systems will surely have been modified over the long span of our evolution.

A related literature deals with various detailed aspects of how these norms may have evolved.[14] Some of this literature is also based on evolutionary theory[15], some from neuroscience[16], some from child development[17] and some from the study of primates .[18]

Hauser (2006) argues that there is a deep structure to moral values, akin to the notion of a template in language[19] while Deacon (1997) argues instead that language and the brain co-evolve. [20]

Since language evolves very quickly (McWhorter, 2001; Deutcher, 2006), we might also expect moral values to change fairly rapidly, at least in the period during which language itself was evolving. In fact there is empirical evidence that cooperative behavior as well as notions of fairness vary significantly across different societies.[21] While there may be fundamental aspects of morality and "altruism," in particular, held in common across many societies, there is variation in how these are articulated. Gazzaniga (2008) suggests that moral values can be described in terms of various *modules*: reciprocity, suffering (or empa-

[11] Strong reciprocity means the punishment of those who do not cooperate.

[12] Indeed, White et al.( 2009) present evidence of a high degree of cooperation among a very early hominid, *Ardipithecus ramidus*, dating back about 4MYBP (million years before the present). The evidence includes anatomical data which allows for inferences about the behavioral characteristics of these early hominids.

[13] Gintis cites the work of Robson and Kaplan (2003) who use an economic model to estimate the correlation between brain size and life expectancy ( a measure of efficiencey). In this context, the increase in brain size is driven by the requirement to solve complex cooperative games against nature.

[14] "Culture" can be thought of as the social context in which these norms are maintained. See Cavalli-Sforza and Feldman, 1981; Wilson (1978); Lumsden and Wilson (1981). .

[15] Gigerenzer 2007; Ridley, 1998; Wright 1994, 2000; Boyd and Richerson, 2005; Jablonka and Lamb, 2006.

[16] Gazzaniga, 2008.

[17] Bloom, 2004, 2010.

[18] De Waal, 1996, 2006.

[19] This is derived from the work of Chomsky (1972) and Pinker (1997, 1999),

[20] See also Bowles et al. (2003), Bowles (2006), Choi and Bowles (2007) and Pinker and Bloom (1990) who present models of the co-evolution of language, institutions and cooperation.

[21] See Henrich et al. (2004, 2005), which reports on experiments in fifteen "small-scale societies," using the game theoretic tools of the "prisoners' dilemma," the "ultimatum game," etc. See also the review by Samuelson ( 2005).

thy), hierarchy, in-group and outgroup coalition, and purity/ disgust. These modules can be combined in different ways with different emphases.

Currently this literature lacks a fundamental unifying theoretical structure, although the earlier work by George Price ([1971], 1995) gave a formal stochastic model relating fitness to traits that can be used to study selection in any evolving process, including economic development[22]

Binmore (2005, 2007) makes a number of very relevant comments on norms and culturally determined values, on the basis of notions from evolutionary game theory.[23] The most important point is that norms can be seen as particular kinds of equilibrium selection mechanisms that are generated by the nature of the technology that the society has developed, and the enviroment in which it is located. So hunter-gatherer societies will tend to exhibit equity or egalitarian share and effort norms.[24] Agricultural, or *limited access societies*, of the kind discussed by North, Wallis and Weingast (2009), will focus on norms associated with hierarchy, power, honor and obedience. *Open access societies* will focus on norms of freedom, fair play and merit.[25]

The industrial development that occurred in Britain and the US in the past brought these equity norms into contest with economic principles of "efficiency" and the free market.[26] The recent technological changes have exacerbated economic inequality, particularly in the US.[27]

These different normative beliefs about the proper balance between efficiency and equity are just as important as preferences in affecting political choice.

In any polity the underlying moral beliefs can be fairly heterogenous, reflecting these different emphases on efficiency, equality, freedom, and hierarchy.[28] There is still no generally accepted theory about how these beliefs are propagated and transformed in a society. It has been suggested that they can be regarded as "memes," acting like genes, mutating and multiplying under selection pressure.[29] Indeed scientific notions, such as that of "meme" itself, as well as moral principles can be thought of memes.[30] Bikchandani et al.(1992, 1998) write about *fads* and *information cascades*. Schofield (2006) introduced the notion of belief cascades in an attempt to capture the idea that such changes of political beliefs can be the result of new theories about how the world works,

[22] Price's work was used by Maynard Smith (1972, 1982) to develop the idea of an evolutionary stable strategy, and by Hamilton 1970) in a model of spite. See Frank (1995), Hamilton (1995) and Harman (2010) for discussion of Price's work.

[23] See also Binmore (2009).

[24] Wrangham (2010), for example, argues that the use of fire for cooking enhanced sharing norms.

[25] Societies with free markets and extended franchise are termed open access societies by North et al. (2009).

[26] Mokyr (2010) charts the changes in belief that occurred in Britain in the period of industrialization, 1700-1850. David Kennedy (2001) gives a historical account of the political changes that occurred in the U.S. in the period from 1900 to 1945.

[27] Reich (2007, 2010).

[28] Westen (2007) comments on the influence of moral values on political choice.

[29] See Dawkins (1976) and later work by Dennett (1995) and Blackmore (2000).

[30] Dennett (2003).

constructed in order to deal with the quandaries that the society faces.[31]

As we have suggested above, political beliefs will be affected by expectations about the future, as well as interpretation of the past. The collapse of the Soviet Empire in 1989 first brought about a sense of relief, as exemplified by the notion of the triumphant "end of history" of Fukayama (1992), and a period of stability and globalization. Below, we refer to this as the *holocene*, lasting most recently from about 1990 until 2001. However, American hegemony was short-lived. The "Clash of Civilizations" (Huntington, 1998) after 2001, the recent recession of 2008/9, and the current fears over the effects of climate change and international disorder, remind us of the earlier fears, in the inter war years, about the over-rapid development of science and the possibility of civilization's collapse through war. In hindsight, these earlier fears in the 1930's over future war were entirely justified.

# 2 Uncertainty

Many authors, from Paul Kennedy (1987) on, have discussed the similarities and differences between the Roman, British and American empires in terms of military over-reach and hubris.[32] Indeed, Ferguson (2005) uses an interesting typology of empire, distinguishing between those that are autocratic, aristocratic, oligarchic or democratic, and whether they are based on the prncipal factors of land, labor or capital. While there are obvious differences between these empires, Ferguson (2010) also suggests that the American empire, like earlier ones, may collapse in a chaotic fashion, possibly bringing about catastrophe.

He notes that the total US federal debt increased from $5 trillion in 1992 to $7 trillion (about 70% of GDP) in 2000, to $17 trillion (about 117% of GDP) in 2010. In fiscal year 2000 there was a federal surplus of $236 billion, which by 2004 had become a deficit of about $520 billion, partly because of the Bush tax cuts.The estimated federal deficit for the fiscal year ending Sept. 30, 2010, is $1.47 trillion, over 10% of GDP. Stiglitz and Bilmes (2008) laid part of the blame for the increasing federal deficit on the Iraq war, citing a total estimated past and future cost of $3 trillion.[33]

Like Kennedy and Ferguson, Bacevich (2010) develops this theme of military over-reach, suggesting that the US has become wedded to permanent war. He argues that the recent crisis, and the problem of debt, has made this imperial military and economic strategy impossible for the US to maintain. In terms of

[31] Indeed, much of the literature cited above can be seen as part of an extensive effort to construct a formal theory of moral values and beliefs based on the mathematical model of game theory.

[32] See Ferguson (2001, 2002, 2004), Zakaria (2003), James (2006), Murphy (2007), and Bacevich (2008, 2010)

[33] The Stockholm International Peace Research Institute estimated that the US 2009 military budget was $663 billion about 4.3% of GDP. An estimate for the Department of Defense budget for fiscal year 2010 is $685 billion. This expenditure has risen since 1999 when it was about 3%. However, other defense spending on Iraq and Afghanistan has brought the total for 2010 to about $ 1 trillion, about 7.5% of GDP. See the discussion in Johnson (2004) on militarism.

economic decline, the trade deficit of the United States with China increased from $103 billion in 2002 to $268 billion in 2008, though it dropped to $227 billion in 2009. China now holds about $900 billion in US debt, followed by Japan with $800 billion. The rest of the US debt is spread between OPEC, Brazil, Hong Kong and Taiwan. We seem to be entering a new type of multipolar world, with no hegemon, and potential conflicts between regional powers such as China, India, Brazil, as well as the oil rich states of the Middle East and Russia.[34]

The 1990's may, in the future, seem like an economic "holocene," maintained by the economic and military hegemony of the United States. An important aspect of this dominance lay in the belief in the "soft power" of the US, namely the validity of the principles of democracy and capitalism.[35] The double shock of 2001 and the crisis of 2008/9 has brought this period to an end, and it may well be that without such a hegemon, political *and* economic instability will be exacerbated.

In recent years, fears over an uncertain future have been have been compounded by changes in our understanding about how the world, and society really work. First, at the level of the logic of science, Prigogine (1996) has used chaos theory to argue against the predictability and determinism of a Newtonian universe. Von Hayek (1974) made a related point, in his Nobel lecture, about the difference between economics and what he considered to be the way natural science works:

> While in the physical sciences it is generally assumed, probably with good reason, that any important factor which determines the observed events will itself be directly observable and measurable, in the study of such complex phenomena as the market, which depend on the actions of many individuals, all the circumstances which will determine the outcome of a process... will hardly ever be fully known or measurable.

For Milton Friedman (1953) on the contrary, it was irrelevant whether economic theory made unrealistic assumptions, as long as it worked. But the recent recession strongly suggests that economic theory just does not work.

The collapse of belief in the logic of economic theory is exemplified by the confession of Alan Greenspan, former chairman of the Federal Reserve, to Congress in 2008, when asked whether his ideology about market equilibrium was right, and working, replied that he was shocked to learn that it was wrong.[36] He has also commented that "our current understanding of the future is extremely limited."

[34] See Jacques (2010) on the rise of China as a rival, and Shapiro (2008) on the changes in the balance of power as a result of globalization.

[35] It seems that full democracy is far more difficult to build than was originally believed. The economic crisis has also led many to infer that the economic model underlying capitalism is completely wrong.

[36] The comments by von Hayek and Greenspan are cited in Ramo (2009).

In the face of this uncertainty about the future, we argue that it behoves us to attempt to create an ethical basis for our actions when they have such possibly dire consequences. There may be disagreements about an ethical foundation for society, with a pure free market orientation at one pole, and an extremely egalitarian focus at the other. Almost all people believe in some version of "propinquity", my family, my neighborhood, my country. On the other hand, there is belief that the future, our children, and future generations, should be protected from our greed. As an illustration, both Jefferson and Condorcet argued that debt or other liabilities should not be incurred if they could not be paid off in a generation. (Their argument was that in about a generation of 20 years, half the population would have changed through birth and death.) This is a version of "intergenerational utilitarianism" proposed by Collier (2010).

This principle asserts that we should be "fair" towards the future, by taking into account the expected overall utility of future generations.[37] A natural consequence of this principle is that we should avoid destroying the world we live in for short term gain. Note that this is a utility principle, not an income principle. If climate change is expected to have greatest impact on the poor, in Africa say, then this principle implies that costs should be borne in the developed economies to offset the likely enormous utility costs of the poor in the future. One aspect of this calculation is the appropriate discount parameter to use. Collier suggests that if we do choose to burden the future, then we should lay aside assets to cover the anticipated future costs. Relatively risk free assets such as U.S.Treasury bonds give about 3 to 4% return, so this can be used to infer the appropriate transfer to the future. Posner (2005) estimates that the cost of climate change could reach about $8 trillion a year, so discounted at 3%/annum would give a total cost of about $65 trillion. If we follow Collier (2010) and do not discount the future then the total cost would be astronomical. An ancillary calculation made by Collier is that when we deplete non-renewable natural resources, oil, minerals etc. then we should also lay aside economic assets, namely investment capital, to cover the fact that these resources will not be available to the future.

Finally, carbon, generated by our own economic activity, is a burden, a negative externality, that will affect the future, through its impact on climete. One way to cover the transfers to the future would be through a carbon tax. Since the developed economies currently produce the bulk of $CO_2$,a carbon tax would have the beneficial effect of somewhat reducing consumption, in these economies, of carbon based fuels, and this would make non carbon fuels more viable. Collier suggests a tax of $40/ton of carbon emitted.[38] Such a tax has the advantage that if estimated costs to the future rise, then tha tax rate can be adjusted. One further aspect of this way of dealing with the externality is

[37] See also the argument in Chichilnisky (1996).

[38] Total US emissions are about 5.6 million metric tons/ annum. One US gallon of gasoline costs $2.70 and emits about 20lb of $CO_2$ when combusted. If the USA imposed a tax of $40 on every quantity of gasoline that would emit one metric tonne of $CO_2$ during combustion, the carbon tax on this gallon of gasoline would be 22 cents, an 8% increase. An average motorist uses about 400 gallons/annum and so emits less than 4 tons of $CO_2$/ annum.

the matter of uncertainty. There is a great deal of uncertainty at present, over the effects of economic activity. Even with the mathematical models of climate change that we discuss below, this uncertainty will persist. If our activities cause even more uncertainty over the consequences of our actions, then we should further compensate the future.

Stern argues that we should be extremely risk averse over climate effects. Since future generations will face the costs of our decisions, we too should be uncertainty averse, and devote resources to the attempt at gauging these costs. One of the problems with dealing with climate change is that it concerns decision making in what are known as "large worlds." Models of decision making work well in "small worlds" where probabilities can be estimated. Chilichilnisky (2009, 2010) provides the beginning of a theory of decision-making in such "large worlds" involving uncertain, potentially disasterous "black swan" events.[39] In our opinion, uncertainty about the future resides in the possibility that the dynamic systems that will determine our future are, in fact, *chaotic*.

From the time of Newton to Laplace, the dominant notion in science was *determinism.* In the developing social sciences and economics, statistics provided a way of interpreting and controlling events. But the efforts to extend the simple Newtonian model of celestial mechanics by Poincaré in the late nineteenth century showed that apparently deterministic physical systems could be deeply chaotic or non-predictable.[40] An essentially mathematical theory that has been developed in the few decades or so is *complexity or chaos* theory, dealing with the non-deterministic properties of dynamic systems.[41] This theory is only a few years old but it already forces us to rethink habits of mind about how the world and society work.

One area where this theory has proved of use is in understanding the complex positive and negative feedback mechanisms that govern climate and its effect on human evolution. Section 3 suggests how celestial mechanisms to do the Earth's orbit interact with geological processes on the planet to affect the $CO_2$ level. For example, the uplift of the Tibetan plateau has acted to remove $CO_2$ over the last 40 million years, inducing oscillations between glacial and interglacial periods. The current ice age, the Pliocene-Quaternary glaciation, started about 2.58 million years ago during the late Pliocene. The planet generally became drier during this ice age, and the ancestors of our species,*Homo habilis* (from *2.5* MYBP*) and Homo erectus* (from 1.8 MYBP), adapted to the new savanah conditions in Africa. Remains of Homo erectus have been found in Java dating to 1.6 MYBP. In Section 1.1 we have mentioned the extensive literature on the evolution of these early hominids. It has been argued that *Homo erectus* included meat in its diet, and used fire, thus increasing the energy available to

[39] In fact, Binmore (2009) argues that decision making in "large worlds" faces epistemic problems resulting from the Gödel-Turing Theorem.

[40] See Mlodinow (2008) for a discussion of chaos and randomness and Thuan (2000) for a discussion of the applicability of the idea of chaos in scientific revolutions.

[41] See Prigogine (1997) for a philosophical discussion of the general ideas underlying this theory, and Beinhocker (2006) for a wide ranging application of some of these ideas to economics.

became an efficient and cooperative predator.[42]

Mitochondrial analysis from modern humans suggests a common ancestor in Africa about 200KYBP.[43] Equipped with language, a system of moral values, associated with cooperation, and a technology of increasingly sophisticated tools, this early hunter gatherer spread throughout the planet. It is thought that there were two conduits out Africa, about 70KYBP, one from the Horn of Africa and one across the Sinai peninsula into Asia.

From about 90 to 10 KYBP, climate became highly unstable. Without our ancestors' braininess, language and culture, the uncertainty induced by climatic chaos could have driven *Homo sapiens* to extinction. Indeed, it has been argued that an eruption in Sumatra about 70KYBP induced an instant ice age and almost killed off all *H.sapiens.* It may well have finished off *H. erectus.*[44] The human population is estimated to be between 250,000 and 500,00 in 62KYBP, slowly increasing to about 6 million in 12KYBP, at the end of the ice age.

# 3 The Holocene and the Anthropocene

Climatic amelioration at this beginning of the *Holocene* in 12KYBP meant warm, wet conditions over much of Eurasia allowing for the transformation of hunter gatherer society to agricultural communities in the Middle East. After the transition, human population increased to about 60 million in 3KYBP (the beginning of the bronze age) and then to about 240 million in 2KYBP.

Farming appeared in the Fertile Crescent about 11.5KYBP with wheat, barley, then peas and lentils. It spread to Egypt by 9.5KYBP, and had independent origin in China and India about the same time, but much later in the New World (Diamond, 1997). Pastoral agriculture appeared about the same time: goats were tamed in Iran by 12KYBP, sheep in Iraq by 9KYBP, and various breeds of cattle in the middle east and India by 8KYBP.

Cochran and Harpending (2009) argue that this population explosion was coupled with both cultural and genetic transformations. In particular, the change from hunter gatherer society to agriculture and "closed access society" was associated not only with a dramatic increase in population and "total economic product," but also in inequality, and the division of society into poorly fed peasants and military and technological elites.[45] The induced Malthusian constraint meant that the "real wage" tended to decline except at catastrophic times when population crashed because of plague, as in the fourteenth century.[46]

From about 1600 our very braininess triggered a scientific explosion in the development of mathematical languages which allowed for the deeper analysis of the world and society. The beginnings of the agricultural and industrial revolutions in the United Kingdom from 1700 on and then later in the United

[42] Wrangham (2009)

[43] Cann et al (1987). We use KYBP to mean thousand years before the present.

[44] Such a catastrophic event would cause a bottleneck in the development of *H.sapiens*, and may have induced a sudden and very rapid transformation in the evolutionary path.

[45] See North et al. (2009).

[46] See Schofield (2010).

States, and the transition to "open access societies" triggered rapid economic and population growth, but also initially caused an increase in inequality.[47] This was reversed from about 1860, and further economic growth induced swift changes in the balance between capital and labor during the late nineteenth and early twentieth centuries. In 1860, GDP/capita in both the UK and the US was about $2800, rising in parallel to about $5500 by 1914, and staying roughly constant during the times of turmoil until the 1930's. After World War II, GDP/capita started to rise rapidly from $9.5K in 1950 to $30K by 2003 in the US, and from $7K to $21K in the UK.[48] Until about 1970, this pattern of growth seems to have lessened the degree of inequality in the developed economies.[49]

The period from 1990 to the present can be seen as an economic holocene. In the same way we may see the previous long periods of growth in these two periods from 1860 to 1914 and from 1950 until about 2006 as *economic and political holocenes.* Both periods were characterizd by hegemonic leadership, first by Great Britain and then by the United States. Maddison estimates that world population grew from a billion in 1820 to about 1.8 billion in 1914. For this most recent period from 1950, world population grew from 2.5 billion to 6.8 billion. The population growth rate increased from about 1.5% in 1950 to over 2% in 1971, and has gradually fallen to 1.1% at present. This recent population growth has induced a number of changes in the world political economy.

First, technological development has shifted the balance of economic power both within developed economies and between the developed and less developed economies. Second, inequality within the developed polities has tended to increase from about 1970, partly because of the premium put on technological skill and partly due to the change in the age distribution of the population. This has been exacerbated by the transfer of manufacturing comparative advantage from developed to less developed countries, particularly China and India.

As commented on above, these global changes have made political economic conflict much more difficult to resolve, and have suggested similarities between the present and the end of the last economic holocene in 1914. It is unlikely that we face anything like World War I, but it does now seems that the world and our society are much more complex than implied by the various social theories that were developed to facilitate growth in the past. It is very unclear what triggered the transition to open access society after 1700, to be followed by the disorder of the interwar period and then the astonishing changes after 1950.[50]

[47] For Britain, Maddison (2007) estimates that GDP/capita grew from $1250 in 1700 to $1750 in 1820, measured in 1990 international Geary Khanis (GK) dollars. However, estimates of the real wage of building workers in 1700 and 1820 by Clark (2007) are identical. This implies inequality increased. The estimates by Rourke and Williamson (1999) suggest inequality in the US only started to increase after 1890. See also Schofield (2008).

[48] These are the estimates by Maddison (2007), measured in 1990 international Geary Khanis dollars.

[49] Reich (2007) notes that the richest 1% received about 20% of income in 1927 but only 10% in 1970.

[50] Acemoglu and Robinson (2006) and Mokyr (2010) give interesting accounts of the first

We have suggested that there are elements of the world and society, such as climate and the pattern of economic development, that are chaotic. This presents us with quandaries about how to make decisions with regard to the future. The most mathematical of our theories about society, namely general equilibrium, may also be deeply flawed, and we may need to think again about how to orchestrate our institutions to guard against risk.

Since chaos and uncertainty are inextricably linked, a discussion of varieties of chaos can suggest to us why the future is so uncertain, and perhaps provide a better understanding of how to deal with the externalities that we are currently imposing on future generations.[51]

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period, and there are many accounts of the second.

[51] Indeed, according to Hawking and Mlodonow (2010), without a theory that builds on chaos and uncertainty, we will have no understanding of our future.

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