DOES *HOMO SAPIENS* NEED A RECIPE FOR SURVIVAL? DO WE HAVE ONE?

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Abstract: *It is argued that the natural and human vicissitudes of the Northern Hemisphere—or at least western European history between 1315 and 1648—provide a preview of the sort of consequences for humanity and its demography that will result from the serious if not catastrophic climate change that is now anticipated by the Intergovernmental Panel on Climate Change (IPCC). Game theory suggests that at least some nation-state players in the strategic problem that climate change raises will not choose Nash equilibria that mitigate the problem. The only feasible solution will be the discovery or invention of some non-greenhouse-gas-emitting energy source so cheap that its owner will be indifferent to free-riding by all other users of energy. Recent efforts to develop fusion reactors do not provide much hope for this eventuality.*

KEY WORDS: climate change, European history, little ice age, game theory, "good ideas," nuclear fusion

"Everybody always talks about the weather. But nobody does anything about it."

—not Mark Twain

I. Introduction

Relatively obvious considerations from game theory, public choice theory, and international relations theory strongly suggest that the problem of climate change will not be solved by policy-driven international enforced agreement. We should therefore expect something like one of the worst-case scenarios the Intergovernmental Panel on Climate Change (IPCC) envisions to characterize the next two or three centuries of human history. To prepare ourselves at least intellectually for what may happen, it is worth reviewing the course of the centuries-long global—or at least continental—crisis. What happened in Europe and the Northern hemisphere between 1315 and 1648 A.D. was a largely climate/weather and natural disaster scenario, including substantial anthropocentric environmental impacts, that prefigures the next few centuries. This essay reports the recent findings from economic history and demography about this catastrophic period and its systematic impact. The lessons we may draw from this period are at least sobering, but they suggest that if little is done to mitigate global climate change, it will doom

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mankind to no more than a few centuries of recovery, in which there will be unstoppable population movements to developed nations from non-Western regions.

The likelihood that national and international government policy will mitigate climate change and its effects is, I shall argue, poor. The only event that could prevent, mitigate, or eventually undo the climatic damage will be the provision of a private production good that reduces greenhouse gases (GHGs) and brings ambient temperatures back to early twenty-first century levels. The production good in question is the "formula" for low-cost fusion power; the likelihood of its production at sufficiently low cost and high quantities before the end of the century is very low. By then, it will be too late to mitigate many of the effects of climate change.

II. 1315–1648 A.D.: A Short History of Ecological and Climatological Crises and Their Effects on Humans

Even the worst-case scenario of global climate change is not going to threaten metazoan life.[1] It will, however, select for and select against strongly among members of many species, probably including humans.

To see how human populations have responded in relatively recent history to global crises of environmental change and epidemic diseases, we can turn to the beginning of the fourteenth century and then track just the European calamities of the next three hundred years. The whole period, as well as its major episodes, are material to any preview of the coming climate calamity. Of course, there are many periods in recorded human history when warfare especially (in east Asia, in particular) has killed off a much larger number of people than died during the 350 years in Europe after 1315. However, over this period in Europe, the human costs are ultimately to be credited to environmental harms exacerbated by individual and collective human responses to them.

In 1315 it began raining in northern Europe; it did not seem to have stopped for three food-and-fodder growing seasons. Immediately prior to that, a sustained warming period that lasted about 250 years was marked by

[1] One need only contemplate the vicissitudes metazoan life has dealt with to see that it is capable of surviving vastly greater changes than can be expected even on the worst scenario of global climate change. Consider the mass extinction of the Permian-Triassic 250 million years ago, a relatively recent event, given the age of the Earth—4 billion years, with the first appearance of cellular life 3.5 billion years ago. There have been several other mass extinction events since this one that killed off 90 percent of all extant species. Even so, it only took 30 million years for vertebrates to recover. This subphylum underwent several other periods of global catastrophe that probably produced severe bottlenecks in the evolutionary tree. Even the most recent Cretaceous-Tertiary extinction owing to asteroid impact (and perhaps simultaneous volcanic eruptions) extinguished 75 percent of all extant species, while making space for the mammalian radiation that produced us.

increased European populations. Some have suggested that by 1300 European populations had reached carrying capacity—that is, long-term maximum population density—not exceeded again for 450 years.[2] That was followed by twenty years of severe weather, of which the worst was the "Great Famine" period. The first year of poor growing conditions was weathered, but too little seed was available for the next and persistent rains prevented growth in any case. Knock-on effects—including lack of manure and a murrain—led to the pestilential dying off of livestock (especially oxen for plowing) and reduction of wool for weavers, causing shortfalls across the region and the economy.[3] Even salt for food storage became unavailable owing to wet conditions throughout the period and region.[4] As with previous climatic changes, the period was coincident with a severe eruption at Mount Tarawera in New Zealand.[5] Population losses north of Italy and west of the Urals from the Great Famine are estimated at 10 percent and were probably higher in Britain.[6] But for what happened next, the Great Famine would have been the greatest natural crisis ever to have befallen Europe.

Studying the Great Famine, Ioannis Charalampopoulos and Fotoula Droulia sketch a network of causal linkages that were instantiated in Europe as a result of the events of 1315–1320. Weather-reduced crops and the resulting food shortage generated an iterating cycle of famine; social and political unrest; war, revolution, and other regime changes; and finally migration.[7]

Europe had not recovered from the Great Famine when it was assaulted by the Black Death; the outbreak of Bubonic Plague almost certainly was carried from the eastern Mediterranean in 1348. This was by itself the greatest global crisis of recorded history. Subject to a great deal of subsequent discussion, only recently have quantitative methods and modern methods of inquiry been applied to such data as it left. Mark Koyama, Remi Jedwab, and Noel Johnson's 2019 estimate, widely prefigured by earlier studies, is that 40 percent of the European population died between 1347 and 1352, including losses of more than 50 percent in two years in Spain, France, Italy, and Britain. Focusing on urban centers, they "calculate a 38.9% mortality rate for the 274 localities with mortality

[2] Guido Alfani and Cormac Grada, "The Timing and Causes of Famines in Europe," *Nature Sustainability* 1 (2018): 284.

[3] William Chester Jordan, *The Great Famine: Northern Europe in the Early Fourteenth Century* (Princeton, NJ: Princeton University Press, 1996).

[4] Ian Kershaw, "The Great Famine and Agrarian Crisis in England 1315–1322," *Past & Present* 59, no. 1 (1973): 9.

[5] I. A. Nairn et al., "Rhyolite Magma Processes of the ~AD 1315 Kaharoa Eruption Episode, Tarawera Volcano, New Zealand," *Journal of Volcanology and Geothermal Research* 131, nos. 3–4 (2004): 265–94.

[6] Alfani and Grada, "The Timing and Causes of Famines in Europe," 284.

[7] Ioannis Charalampopoulos and Fotoula Droulia, "The Agro-Meteorological Caused Famines as an Evolutionary Factor in the Formation of Civilization and History: Representative Cases in Europe," *Climate* 9, no. 1 (2021): 327.

data."[8] World population levels are estimated to have declined from 475 million to 375 million in that period. Koyama, Jedwab, and Johnson set out to quantify the spatial and economic effects of the Black Death on the next two centuries of European development. They note that "[t]he Black Death was a comparatively 'pure' population shock. Unlike other shocks … buildings and physical capital were not destroyed and the event itself did not target a particular social, age, gender, ethnic or skill group."[9] This makes the Black Death perhaps even more indicative of the sort of effects global climate change may produce than does the weather-caused Great Famine, which initially and disproportionately affected the agricultural economy and demography.

It is worth noting that overall impacts of climate change on agricultural productivity quantities depend on the size of the temperature rise, but they are not expected to be great, while regional impact on output may be more marked.[10] On the other hand, the relatively brief period of maximal impact of the plague pandemic—only about five years—may undermine some of its relevance to assessing the impact of a century or longer period of extreme warming on everyone. Compiling data from the 165 largest cities, with 60 percent of the total urban population of Europe, Koyama, Jedwab, and Johnson found a return to pre-plague population levels by the sixteenth century. Rural populations close to urban centers required a further period of a century to recover. Interestingly, settlements were more frequently abandoned in areas of low mortality, particularly those regions distant from urban areas: "In other words, recovery was not simply driven by the higher fertility and lower mortality effects described in the macrohistorical literature."[11] Rates of recovery for cities varied, depending on the interaction between mortality levels and differences in productive resources and local geographic advantages that favored trade. In addition, "[e]conometric evidence [shows] that the Black Death had strong spatial-economic effects in the short-run, but no such effects in the long-run."[12] However, this is because the recovery of cities was driven largely by migration, not local fertility. These authors' "analysis suggests that the Black Death led to a reset consistent with a potentially superior population distribution."[13] "Superior" here presumably means economically more productive.

[8] Mark Koyama, Remi Jedwab, and Noel Johnson, "Pandemics, Places, and Populations: Evidence from the Black Death" (Discussion Paper 13523, Centre for Economic Policy Research, 2019), 8, https://economics.yale.edu/sites/default/files/cepr-dp13523_adans.pdf.

[9] Koyama, Jedwab, and Johnson, "Pandemics, Places, and Populations," 2.

[10] Francesco Bosello and Jian Zhang, "Assessing Climate Change Impacts: Agriculture" (CMCC Research Paper No. WP2, Fondazione Eni Enrico Mattei, 2005), https://www.econstor.eu/bitstream/10419/73909/1/NDL2005-094.pdf.

[11] Koyama, Jedwab, and Johnson, "Pandemics, Places, and Populations," 3.

[12] Koyama, Jedwab, and Johnson, "Pandemics, Places, and Populations," 6.

[13] Koyama, Jedwab, and Johnson, "Pandemics, Places, and Populations," 4.

With an eye to implications of their study for contemporary issues, including the impact of climate change, Koyama, Jedwab, and Johnson conclude:

> Finally, our results are particularly relevant for the developing world today. Indeed, it can be argued that today's poor economies disproportionately rely on fixed factors of production similar to the ones we identify in our context. This could explain why mortality increases observed in the present day often have positive effects … and why population increases may have negative effects …. While this is likely true for rural areas, one could also argue that poor country cities are to some extent "Malthusian". … Lastly, our context of decentralized polities with weak state capacity is similar to that observed in poor countries today.[14]

The Black Death was arguably a public harm whose direct and indirect effects were consumed nonrivalrously and nonexcludably, except by small numbers of wealthy and highly risk-averse individuals[15] and those living in isolated regions of Europe not engaged in any trade with other regions of the continent.

The Hundred Years War—which was actually three periods of active warfare—was not a direct effect of the Black Death. It began a decade before the Black Death and ended in 1453. This conflict between England and France persisted for about 130 years and killed three million people, adding substantially to the reduction in population. By the end of the period, the estimated losses for France were 50 percent (including 65 percent of the population of Paris) and a one-third loss for Britain, from a population already reduced by famine and disease.[16] Compared to this, the British War of the Roses, which lasted thirty years, was a "drop in the bucket," but the thirty-year-long Catholic-Protestant conflict in France, culminating in 1598 in the Edict of Nantes, probably led to the death of over three million people.

Meanwhile, the Iberian conquest of North and South America—also known as "the Columbian Exchange"—was having so great a population impact on the Western hemisphere that its ecological ramifications for Europe continued the environmental crisis that the Great Famine had started. The magnitude and climatological impact of the disease-caused depopulation of the entire Western hemisphere over a relatively brief period has only become evidentially manifest in the past few decades. The depopulation is staggering in its magnitude, speed, and environmental impact. It

[14] Koyama, Jedwab, and Johnson, "Pandemics, Places, and Populations," 6.

[15] Cf. Giovanni Boccaccio's 1353 *The Decameron*, trans. G. H. McWilliam (New York: Penguin, 1972).

[16] Peter Turchin, *Historical Dynamics: Why States Rise and Fall* (Princeton, NJ: Princeton University Press, 2003), 179.

is likely to have produced the so-called European "Little Ice Age." The dating of this period from roughly 1420 to 1820 is somewhat arbitrary, but the period of lowest mean temperature begins in 1600 and lasts about one century. Interest in anthropogenic climate change has led many, including the IPCC, to seek causal factors for the climatic variation of that period. Moreover, there is reason to suppose that the anthropogenically induced cooling interrupted a long-term process of anthropogenic warming that has delayed the onset of an expected period of glaciation. William Ruddiman writes:

> The hypothesis advanced here is that the Anthropocene actually began thousands of years ago as a result of the discovery of agriculture and subsequent technological innovations in the practice of farming. This alternate view draws on two lines of evidence. First, the orbitally controlled variations in CO_2 and CH_4 concentrations that had previously prevailed for several hundred thousand years fail to explain the anomalous gas trends that developed in the middle and late Holocene. Second, evidence from paleontology, archeology, geology, history, and cultural anthropology shows that human alterations of Eurasian landscapes began at a small scale during the late stone age 8000 to 6000 years ago and then grew much larger during the subsequent bronze and iron ages. The initiation and intensification of these human impacts coincide with, and provide a plausible explanation for, the divergence of the ice-core CO_2 and CH_4 concentrations from the natural trends predicted by Earth-orbital changes.[17]

The European conquest of the Western hemisphere began from the first moment of contact, with the transmission of disease, particularly animal-borne diseases to which Europeans had long before become immune, beginning with smallpox and chicken pox, but including the common cold, influenzas, measles, and malaria.[18] Alexander Koch and his coauthors summarize a detailed study of the impact on global climate of the European arrival in the Western hemisphere in the starkest terms:

> We estimate that 55 million indigenous people died following the European conquest of the Americas beginning in 1492. This led to the abandonment and secondary succession of 56 million hectares of land. We calculate that this led to an additional 7.4 Pg C being removed from the atmosphere and stored on the land surface in the 1500s. This was a change from the 1400s of 9.9 Pg C (5 ppm CO_2). Including feedback

[17] William Ruddiman, "The Anthropogenic Greenhouse Era Began Thousands of Years Ago," *Climatic Change* 61 (2003): 261–62.

[18] Even hugely fatal post-arrival pandemics thought for hundreds of years to have had indigenous origins, have by DNA analysis been established to be European in origin. Ewen Callaway, "Collapse of Aztec Society Linked to Catastrophic Salmonella Outbreak," *Nature* 542, no. 7642 (2017): 404.

> processes, this contributed between 47% and 67% of the 15–22 Pg C (7–10 ppm CO_2) decline in atmospheric CO_2 between 1520 CE and 1610 CE seen in Antarctic ice core records. These changes show that the Great Dying of the Indigenous Peoples of the Americas is necessary for a parsimonious explanation of the anomalous decrease in atmospheric CO_2 at that time and the resulting decline in global surface air temperatures. These changes show that human actions had global impacts on the Earth system in the centuries prior to the Industrial Revolution. Our results also show that this aspect of the Columbian Exchange—the globalisation of diseases—had global impacts on the Earth system, key evidence in the calls for the drop in atmospheric CO_2 at 1610 CE to mark the onset of the Anthropocene epoch …. We conclude that the Great Dying of the Indigenous Peoples of the Americas led to the abandonment of enough cleared land in the Americas that the resulting terrestrial carbon uptake had a detectable impact on both atmospheric CO_2 and global surface air temperatures in the two centuries prior to the Industrial Revolution.[19]

Data on ice core sampling that Koch and his coauthors provide in some of their quantitative and graphic presentations are striking. These show a steady concentration of CO_2 in two different Antarctic locations from about 1000 until 1400 A.D., a sharp decline thereafter at roughly the pre-Columbian population maximum for the Western hemisphere, and a sharp increase from 1520 through 1700—"the indigenous depopulation event"—followed by an equally steep decrease in CO_2 concentrations from 1700 through 1830.[20]

The increase in terrestrial sequestration of carbon dioxide during the period of the sixteenth and seventeenth centuries resulted in the Little Ice Age in Europe, beginning about 1650. In European history, this period is known among historians as "the General Crisis of the Seventeenth century."[21] Subjecting data about sixteen variables during this period for Europe and the Northern Hemisphere to a quantitative analysis, David Zhang and his coauthors identify the causal linkages that reveal climate change as the most important causal variable in the period's catastrophic character. They write:

> Fluctuations of all agro-ecological, socioeconomic, human ecological, and demographic variables corresponded very well with temperature change and were in successive order. The variables of the

[19] Alexander Koch et al., "Earth System Impacts of the European Arrival and Great Dying in the Americas after 1492," *Quaternary Science Reviews* 207 (2019): 13–36.

[20] Koch et al., "Earth System Impact of the European Arrival," 27–29.

[21] The label was probably created by Eric Hobsbawm, but it is usually attributed to H. R. Trevor-Roper, "The General Crisis of the 17th Century," *Past & Present* 16 (1959): 31–64.

> bio-productivity, agricultural production, and food supply per capita (FSPC) sectors responded to temperature change immediately, whereas the social disturbance, war, migration, nutritional status, epidemics, famine, and population sectors responded to the drop in FSPC with a 5- to 30-y time lag.[22]

The authors provide a flow chart for this period[23] remarkably similar to the one Charalampopoulos and Droulia produce for the Great Famine. Zhang and his coauthors' diagram reflects the degree of statistical correlation (by multiple regression analysis) among the variables they subjected to time-series estimations. The feedback effects of population collapse resulted in a 200 percent increase in grain prices, a 250 percent increase in famine and in migration, and a 1,350 percent increase in war fatalities. They also provide an illuminating graph of trends from 1000 to 1900 A.D. in temperature, population growth, famine, war, and epidemics[24] that reveals the 100-year period ending in 1648 to have been even more catastrophic for European civilization than the Great Famine of 1315. In part, the population decline was due to the last crisis event in the 350-year period here discussed: the Thirty Years War that overwhelmed all aspects of most corners of the German kingdoms, principalities, duchies, free cities, and Länder between 1618 and 1648. The demographic decline resulting from that war is difficult to disentangle from both the severe plague that swept through the country between 1634 and 1638 and the Little Ice Age itself. Demographic losses are estimated across a broad range from four to twelve million, with a 20 percent decline in European population. The Swedish campaign in Germany alone resulted in the disappearance of one third of all the towns and villages. By comparison, World War I's death toll in Europe was 5 percent, including Spanish flu deaths.[25] As with other dislocations in this period, the campaigns back and forth across Germany resulted in short- and medium-term sharp declines in land prices, combined with a sharp increase in wheat prices, as agriculture became more difficult, peasants moved to cities, and food supplies decreased.[26] Recovery from the Thirty Years War required sixty years and the end of the Little Ice Age.

The net levels of urban development, agricultural yield, trade, and population had just managed to survive three hundred of the most appalling years of challenge, but at enormous human cost. These levels had not changed much over that period, despite our retrospective celebration of

[22] David Zhang et al., "The Causality Analysis of Climate Change and Large-Scale Human Crisis," *Proceedings of the National Academy of Sciences* 108, no. 42 (2011): 17296–97.
[23] Zhang et al., "The Causality Analysis of Climate Change," 17298.
[24] Zhang et al., "The Causality Analysis of Climate Change," 17300.
[25] Pascal Daudin, "The Thirty Year's War: The First Modern War?" *Humanitarian Law and Policy*, May 23, 2017, https://blogs.icrc.org/law-and-policy/2017/05/23/thirty-years-war-first-modern-war/.
[26] Henry Kamen, "The Economic and Social Consequences of the Thirty Years' War," *Past & Present* 39 (1968): 44–61.

the Renaissance and the Reformation. The former was made possible by the increase in per capita wealth and income that the Bubonic Plague produced, while the latter was the presumptive cause of the Thirty Years War. Populations were lower in Europe at the end of the seventeenth century and the resulting temporary per capita resource and wage increases lasted into the middle of the eighteenth century before beginning to decline again. The rise in population at the end of this period is credited by economic historians to global warming that increased the amount of arable land in Europe as well as to the accelerated industrialization of Europe after 1700. As population began to outstrip agricultural production after the mid-eighteenth century, Malthusian conditions again took hold.[27]

III. The Coming Climate Crisis

The history of these 350 years of interaction between human activity and environmental processes should focus the mind. It is at least an indication of how serious the consequences are for the ways human activity interacts with public harms conferred by natural processes. Rainy weather and plague infestation are initially exogenous forces, but they mix with endogenous ones to produce disaster on a global scale. Then apparently, feedback processes from our activities to those previously exogenous meteorological factors make matters catastrophically worse and for longer periods. On the other hand, humanity survived and Europeans went on to dominate the rest of the planet for another 350 years or so.

Will the coming period of climate change confer harms worse than, as bad as, or less bad than as during 1315–1648? The answer is "probably"; that depends on the magnitude of the temperature change and a cascade of other causal linkages it is impossible to calibrate with any reliability. Referring only to economic effects, a well-known "alarmist" about worst-case scenarios, Martin Weitzman, notes:

> [T]he economics of climate change consists of a very long chain of tenuous inferences fraught with big uncertainties in every link: beginning with unknown base-case GHG [Green House Gases] emissions; then compounded by big uncertainties about how available policies and policy levers will transfer into actual GHG emissions; compounded by big uncertainties about how GHG flow emissions accumulate via the carbon cycle into GHG stock concentrations; compounded by big uncertainties about how and when GHG stock concentrations translate into global mean temperature changes; compounded by big uncertainties about how global mean temperature

[27] Paolo Malanima, *Pre-Modern European Economy: One Thousand Years* (Leiden: Brill Academic Publishers, 2009), 45–46.

> changes decompose into regional climate changes; compounded by big uncertainties about how adaptations to, and mitigations of, climate-change damages are translated into utility changes at a regional level; compounded by big uncertainties about how future regional utility changes are aggregated—and then how they are discounted—to convert everything into expected-present-value global welfare changes.[28]

Weitzman also notes that the effects of GHG emissions are relatively long lasting: 70 percent of the anthropogenic CO_2 emissions remain after ten years, 35 percent after 100 years, 20 percent after 1,000 years, and 10 percent after 10,000 years.[29]

The latest high- or medium-confidence expectations of the IPCC for a 1.5 or 2 degree Celsius (owing to GHG emissions) increase in global temperatures vary across regions. The strongest warming of hot extremes is projected to occur in central and eastern North America, central and southern Europe, the Mediterranean region (including southern Europe, northern Africa, and the Near East), western and central Asia, and southern Africa. The number of exceptionally hot days are expected to increase the most in the tropics; they are expected to already become widespread there at 1.5°C global warming. According to the IPCC:

> Much heavier precipitation is expected in high-latitude regions (e.g., Alaska/western Canada, eastern Canada/ Greenland/Iceland, northern Europe and northern Asia); mountainous regions (e.g., Tibetan Plateau); eastern Asia (including China and Japan); and eastern North America. Heavy precipitation associated with tropical cyclones is projected to be higher at 2°C compared to 1.5°C of global warming. Drought risks, frequency and magnitude are projected to be substantially larger at 2°C than at 1.5°C in the Mediterranean region. A loss of 7–10% of rangeland livestock globally is projected for approximately 2°C of warming. Decreasing food security are projected to become greater as global warming reaches beyond 1.5°C and both ocean warming and acidification increase, with substantial losses likely for coastal livelihoods and industries. Urban heat islands will amplify the impacts of heatwaves in cities (*high confidence*). Vector-borne diseases, such as malaria and dengue fever are projected to increase with warming from 1.5°C to 2°C, including potential shifts in their geographic range. Out-migration in agricultural-dependent communities is positively associated with global temperature (*medium confidence*). The largest reductions in economic growth at 2°C compared to 1.5°C of warming are projected for low- and middle-income countries and regions (the

[28] Martin Weitzman, "Reactions to the Nordhaus Critique" (Discussion Paper 09–11, Harvard Environmental Economics Program, Cambridge, MA, April 2009), 7–8.
[29] Weitzman, "Reactions to the Nordhaus Critique," 15.

> African continent, Southeast Asia, India, Brazil and Mexico) (*low to medium confidence*).[30]

Countries in the tropics and Southern Hemisphere subtropics are projected to experience the largest impacts on economic growth due to climate change, should global warming increase from 1.5°C to 2°C.

Weitzman is well known for having suggested that there is significant risk of a far more catastrophic scenario—a 5 percent chance of temperature rises by 6.4 degrees Celsius—which would be a much greater magnitude change than anything humankind has seen since even before the last Ice Age ended.[31]

Let's assume that the IPCC's estimates are accurate and ignore the truly catastrophic alternative. What is clear is that some regions will suffer immediately more than will other regions. Indeed, so far as agricultural production is concerned, there may even be gainers from global climate change.[32] However, such positive effects will be swamped by direct and spillover effects from the worst consequences for other, more populous regions that will quickly spread to less immediately affected regions. It is safe to say that climate change is a public harm and that limiting temperature change to 2 degrees Celsius or less is a public good. Here, these terms are used in their strict economic sense: nonrivalrous, nonexcludable, and unavoidable consumption in the case of a public bad. In addition to the nonrivalrous, nonexcludable consumption of the public bad, there are spillover effects, including standard externalities imposed on countries and regions that will experience minimal direct climate effects resulting from the impact of the greater dislocations in countries mentioned in the IPCC summary above.

The widespread but nonuniform impact of climate change will most forcefully and dangerously manifest itself in the movement of large numbers of people from developing nations to already developed ones (as occurred during the period 1315–1648). In addition to straining the social safety nets of countries to which these meteorological refugees will come, the prospects for military violence in preventing their entry and internal political strife over policies to respond to these mass population movements, will be among the most serious problems climate change raises for countries with resources to mitigate it direct effects on them.

Can we expect individual and collective agents to respond to the public harms in the same ways humans have responded to catastrophic weather, climate changes, and infection-vectors in the past? Should we expect a cooperative or collaborative response that substantially mitigates these effects? One might suppose that stronger governments and more effective

[30] Intergovernmental Panel on Climate Change, "Global Warming of 1.5°C " (New York: Cambridge University Press, 2019), https://www.ipcc.ch/site/assets/uploads/sites/2/2022/06/SR15_Full_Report_LR.pdf.

[31] Weitzman, "Reactions to the Nordhaus Critique," 8.

[32] See Bosello and Zhang, "Assessing Climate Change Impacts," for projections regarding differing crops in various regions and countries.

intergovernmental cooperation can and will implement the vastly greater knowledge and applied science at humanity's disposal to do so. Humanity was impotent in the face of many or most of the catastrophes that befell it during 1315–1648. We no longer are. One might argue that this accretion of scientific knowledge and technological power makes that period irrelevant to our expectations about the next two hundred years or so. We can do something about the weather, besides talking about it.

IV. The Dismal Scenario of Game Theory

Unlike the case of the global or perhaps only Northern Hemisphere or merely European crisis of the fourteenth through the seventeenth centuries, we know what's coming, its causes, and its consequences—at least to some extent. History is thus a poor guide to how individuals and collectives will respond. Contemporary social science will not do worse than narrative history in its factual and counterfactual projections of how people, peoples, nations, and continents will respond to the coming global crisis. We especially need game theory—the science of strategic interactions—to identify institutions we can use or design that could mitigate the worst costs that the public harm of climate change will impose.

In what follows, let's assume that climate change's increasing average world temperatures by 2 degrees Celsius is a public harm[33] and limiting it to this amount or less is a public good (a good public commodity) that would enhance the welfare of all persons on the planet (though not all equally). Assume also that available steps individuals and collectives could take to produce this public good are less costly than the total benefit to all individuals on the planet, including presumably the psychic rewards, if any, of assurance that as-yet-unborn descendants will be benefited by provision of this public good.

Applying game theory, it is tempting to simplify matters by treating nation-states as the relevant agents that will choose international policies that best serve the interests of their citizens. I believe that this temptation should be resisted. Strong assurance that nations will act against the interests of their citizens comes from international relations theory.

The great puzzle of rational choice modeling in international relations is that wars should never happen. Modeling the rationality of states faced with the choices of war versus alternative means of dispute resolution, results in the conclusion that rational, well-informed, welfare-maximizing states never go to war with one another. Since they do, either nation-states are irrational agents or they are not the relevant rational agents in the war-versus-no-war scenario. Rejecting the claim that nation-states are irrational

[33] This is what Jonathan Anomaly calls a "bad public good," that is, a nonrivalrously, nonexcludably consumed commodity that reduces welfare. See Jonathan Anomaly, "Public Health and Public Goods," *Public Health Ethics* 4, no. 3 (2011): 251–59.

agents, we can conclude that the relevant agents are never these states themselves.[34] The same conclusion should be adopted with respect to other choices faced by sovereign states.

One robust positive finding of international relations theory is that democratic states never go to war with other democratic states. This is the only well-confirmed generalization on which almost all scholars working on international relations agree. By and large, the explanation they offer for this regularity is that nonbelligerence maximizes the interests of the influential individual decision-makers, largely those with substantial economic interests, in democratic states. We need to make the same assumption in applying game theory to the present matter.

Public choice theory also draws the same conclusion. In all matters, the relevant agents in determining the outcome of what appear to be the choices of nation-states or institutions governing them, are the outcome of the aggregation of decisions by individual agents, acting singly or in collectives, whose choices are, in turn, determined by individuals.[35] Public choice theory teaches that government policies are themselves the outcome of choices that reflect the preferences of individual political agents—such as legislators, executives, and judicial officers—all of whom calculate their choices on the basis of self-interest. Since corporations and their owners are in the best position to affect the incentives that legislative, executive, and judicial agents face in making their decisions, the nation-states they control will act in ways that advance the largely corporate interests that are in a position to incentivize bureaucracies and elected officials. The intractable problem in developmental economics known as the "resource curse" provides a powerful example of how difficult it is for any international organization or coalition of nations—or, for that matter, a national political coalition—to put in place incentives to prevent democratic governments, let alone kleptocracies, from trading strategic resources, even when the trade is harmful to almost their entire population. Attempts to design treaties to mitigate the resource curse have not met with any success.[36]

The view that nation-states do not have autonomous roles in securing international public goods and/or preventing public harm, is confirmed by the one case in which a treaty was contrived and adhered to: the Montreal Protocol on chlorofluorocarbons whose emission threatened the ozone layer

[34] For some examples of how intractable this problem is for international relations theory, see James Morrow, "Alliances: Why Write Them Down?" *Annual Review of Political Science* 3 (2000): 63–83; Duncan Snidal, "Coordination versus Prisoners' Dilemma: Implications for International Cooperation and Regimes," *American Political Science Review* 79, no. 4 (1985): 923–42; R. Harrison Wagner, "The Theory of Games and the Balance of Power," *World Politics* 38, no. 4 (1986): 546–76.

[35] For an introduction to public choice theory, see James Buchanan, *Public Choice: The Origins and Development of a Research Program* (Center for Study of Public Choice at George Mason University, Fairfax: VA, 2003); James Buchanan and Gordon Tullock, *The Calculus of Consent* (Ann Arbor, MI: University of Michigan Press, 1962).

[36] For discussion of the "resource curse," see Michael Ross, "What Have We Learned about the Resource Curse?" *Annual Review of Political Science* 18 (2015): 239–59.

protecting people from skin cancers. In this case, only when corporations in the developed world began producing cheaper alternatives to chlorofluorocarbons were their governments able to impose a chlorofluorocarbon production ban worldwide, while indemnifying countries whose production was to be stopped.[37]

As I shall argue, the role of individual self-interest in driving public policy makes it highly certain that international agreements to mitigate climate change are doomed to failure, owing to a multiple-level free-rider problem of the sort well understood in the public goods literature. Suppose that the political leadership of a sufficiently large number of nation-states were to agree to a protocol that secures the public good and prevents the public harm here at issue. The generic Schelling diagram below (see Figure 1) is useful in analyzing the strategic situation. The numbers 1 and 0 on the horizontal axis need to be understood as reflecting conditions that an individual player faces in making a choice: 1 represents that 100 percent of all the other participants in a strategic interaction pursue the public good providing policy, while 0 represents the case in which no other participant pursues this policy.

As there is state sovereignty with no enforcement mechanism in international relations, rational agents directing national policy all have incentives to immediately (or each eventually) direct their states to defect from any public-good providing protocol, so that the only stable Nash equilibrium among strategies is at the lower left of the diagram, where all are worse off. The more states defect from the unstable cooperative equilibrium at the right, the greater the incentive for remaining states to defect. To the left of point k, there is a net cost to states of continuing to honor a climate protocol that consists in the public harm plus the wasted costs of compliance imposed by the protocol. Thus, for an obvious instance, a nation-state such as Russia, whose economic survival turns on the export of petroleum and natural gas, has an overwhelming interest in free-riding on agreements by other producer-countries not to sell. Equally obviously, nation-states that require petroleum and natural gas as productive inputs will defect from agreement not to purchase and use such products. Since the time of the League of Nations (1920–1946), it has repeatedly proved impossible to enforce embargoes on these commodities above all others. Similarly, the congruence of interests between nations that consume coal, such as China, and ones that produce coal, such as Australia, will reinforce benefits from free-riding.

Moreover, some nations' political and economic elites stand to secure net benefits from climate change. Again, the prime example is Russia. It occupies one-sixth of the land area of the planet and is likely to be economically advantaged by global warming in ways that accelerate its negative impact on the rest of the world's climate. As a result of higher temperatures,

[37] Scott Barrett, *Environment and Statecraft* (Oxford: Oxford University Press, 2003).

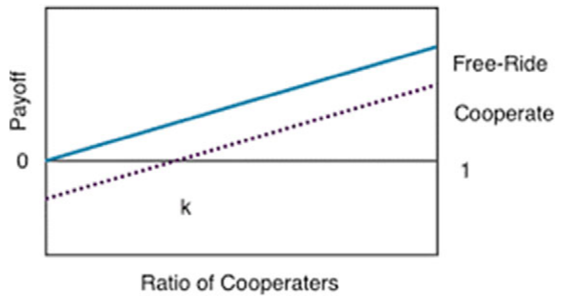

Figure 1. Schelling Diagram.

Russia can expect to substantially increase its arable, temperate farming land in the north; to find it substantially easier and cheaper to reliably transport resources, including oil and gas, from eastern Siberia; and to improve all its coastline access in the Arctic Ocean.[38] If the material benefits of these changes were widely shared, the Russian population might as a whole benefit from global warming levels that will be catastrophic elsewhere. The country—or rather, those who control its economy in their interests—has every reason to make it free-ride.[39]

If, as I hold, nation-states have no independent, systematic, strategic role in securing the public good and avoiding the public harm, we should see Figure 1 above as describing the strategic-interaction problem for individual national and multinational firms engaged in the production and/or consumption of energy inputs that increase global public harms. Self-denying ordinances resulting from agreement among them to mitigate these harms will be unraveled as a result of the same forces that would make climate protocols an unstable equilibrium among nation-states if they were autonomous rational agents.

Contemplate the parallelogram in Figure 1 above. It represents the rewards of free-riding versus cooperating to provide the public good. As public choice theory dictates, corporate interests will expend considerable

[38] Renat Perelet, Serguey Pegov, and Mikhail Yulkin, "Climate Change Russia Country Paper" (Occasional Paper 12, UNDP Human Development Report, 2007), https://hdr.undp.org/system/files/documents/pereletrenatpegovyulkin.pdf.

[39] Differences in payoffs for compliance versus noncompliance in cooperative agreements may result in nations' leaders playing more than one or a few different games with one another in the interests of their political and economic elites. As Jean Hampton has shown, public goods provision may be a matter of single-step and multistep production; in the former case—of which keeping temperatures below a certain level is a good example—the structure of a multiplayer interaction may well be a cooperative stag hunt or an assurance game. See Jean Hampton, "Free-Rider Problems in the Production of Collective Goods," *Economics and Philosophy* 3, no. 2 (1987): 245–73. It would be natural to model the payoffs in such games in ways that make defecting a compelling strategy for Russia, China, and Australia. Their payoffs to hunting the hare instead of the stag are much higher than the payoffs to other economies of doing so. They may even have an interest in other coalitions of countries playing cooperative strategies. This would, however, make their noncompliance more rewarding to themselves.

effort to incentivize governments in the nation-states where they do business to secure these free-rider benefits and to distribute them to their corporate interests.

The speed with which this process takes place will depend on the slope of the two curves in the figure and on the size of region that is represented by the parallelogram. As with most diagrams in economics, this one reflects only qualitative relations; the quantitative character of the line segments—whether linear or exponential, their slope, elasticity, or other properties—can only be guessed it. The pessimistic argument, though, only requires the qualitative relations it conveys.

All this suggests strongly that concerted efforts by coalitions or other collective organizations—of nation-state leaders, corporations, or individuals—to provide the public good and prevent the public harm in question, will be unavailing. The costs of provision and, more important, the payoffs to free-riding are almost certainly too high for international coalitions to remain at the unstable equilibrium required to provide the indivisible and nonrivalrous benefits of climate-change mitigation.

V. Prospects for Mitigating the Climate Crisis as the Positive Externality of a Newly Provided Consumption Good

One feasible, and perhaps the only, solution to the climate change problem will be one that converts the public good into a positive externality produced as the by-product of a nonpublic good, which is a rivalrous, excludable consumable and therefore tradeable between individuals on a conventional market. However, almost the same public goods free-rider problem daunts this approach. As such, the problem of the provision of good ideas mirrors many of those canvased above. A "good idea' is one that pays, that results in the production of some new good or service for which there will be demand or decreases the cost or increases the productivity of inputs to the production of a good or service.

Good ideas are famously able to be nonrivalrously consumed. If I employ crop rotation to increase agricultural productivity, I do not thereby decrease the "amount" of this idea available for you to exploit. Of course, if I hit upon the idea by reflection, tinkering, experimentation, or luck, I can try to keep the idea secret so that I can profit from it exclusively, especially if it is a good idea regarding the use of inputs that cannot be easily reverse-engineered by others. However, protecting a good idea from others by keeping it a trade secret is costly. Consider crop rotation. To keep this good idea secret, I would have to use it in fields far enough away from other farmers that they would not notice. Suppose, instead, that my good idea was manuring fields. I could do this at night to escape detection, but working in the dark will not produce results as good as working in daylight. Excluding others from the exploitation of a good idea is costly and inefficient. The only well-known case of the long-term preservation of a trade secret is the formula for Coca-Cola. Good ideas are “almost public” goods. We may call them “quasi-public goods.”

There are, at present, no privately owned (for example, patented) good ideas available at prices that consumers are willing to pay that will also have the prevention of global climate change as a positive externality. If there were such good ideas, they would presumably have been purchased and implemented by now.

We may exclude geoengineering solutions to the problem of temperature rise from candidate good ideas that have the features required to provide a market solution to the problem of climate change. Even if feasible and without negative environmental consequences of their own, shielding the Earth from the Sun or seeding the oceans with CO_2-absorbing materials are not consumption goods or inputs to consumption goods that could trade on a market. What is more, if they could be implemented and made to work, their mitigating effects would incentivize the continued use of energy sources that increase GHGs. Nuclear fission power is an idea once viewed as “good” and widely implemented in the twentieth century as a productive input to be a source of reliable electric power. However, a variety of its features, including radioactive waste disposal problems, the risk of nuclear accidents, diversion of waste to terrorist action, and threatened geological catastrophes, have resulted in construction and running-cost difficulties that limit its adoption. Whether or not their reaction is reasonable, the unwillingness of consumers of electric power—and, more important, citizens who governments need to satisfy—to purchase nuclear power rules out this idea as a good one for preventing catastrophic climate change. Renewables—such as wind, solar, and geothermal power sources—await packaging with other innovations not yet invented or discovered that will deal with wind variability, solar energy storage, and efficient long-distance transmission (not to mention aesthetic objections). Sellers of all privately owned, publicly tradeable, non-GHG producing energy sources will also have to deal with the incentives of governments and corporations that own large quantities of hydrocarbons to sell hydrocarbon energy sources at prices that will always undercut those of renewable and nuclear fission energy sources. Until the variable cost of extraction and transmission of hydrocarbons exceeds the market price of hydrocarbons, their providers will be able to continue for centuries to undercut the price of alternative clean energy sources. They will have an incentive to do so, since once renewables and other sources of power become cheaper, oil, coal, and natural gas in the ground will be without any market value.

Here is the nub of the problem: What is needed is an altogether new, good, marketable idea for low-cost production of energy. However, the search for one suffers from all the problems that daunt the search for a quasi-public good solution to the problem of mitigating climate change by reducing the use of current means of energy production. National governments, whose leaders know that they will almost certainly be able to benefit from the discovery or invention by others of a "good idea" solution—that is, low-cost energy production—will free-ride on the willingness of other nations or corporations to invest in the research required to produce the idea. The current international intellectual property regime for the protection of good ideas provides ample evidence that no such scheme will work to protect the property rights of the owners or originators of this good idea. National governments willing to steal consumer-good innovations will have less compunction about stealing ideas that can reduce *all* their costs of production, the way low-cost energy production would. The prospects for keeping such good ideas secret are as small as the prospects were of keeping atomic fission secret in the 1940s or preventing nuclear proliferation in the second half of the twentieth century.

The same considerations will, of course, lead corporations and other nongovernmental organizations to decline investing sufficiently in research to attain low-cost energy production. Once their employees discover, develop, and perfect the technology, the incentives others have to secure it by intellectual property theft will be overwhelming. One need only consider the moral and political force that crushed the international intellectual property rights of the pharmaceutical firms that developed the earliest antiretroviral AIDS medications. In the case of catastrophic global warming, a "sweet" technical solution will immediately result in well-grounded demands for its immediate dissemination, along with theft of prototypes or production-run output and reverse-engineering. In the case of designs involving software and coding, the hacking opportunities for free-lance thieves will be immense.

There remains one circumstance under which it would be rational for an individual corporation or consortium to invest in the development of low-cost energy production. Suppose that the expected return to investment in such technology were so great that it would be worth undertaking regardless of the spillover positive externalities to everyone else on the planet that could not be charged for. Suppose that use or sale of the power returns huge rewards to its originators, even if it is immediately copied by many competitors. Such advantages have in the past been cited as rational incentives for governments and business to invest in unpatentable basic scientific research, especially in the life sciences and the development of military technologies. For example, hegemony in advanced pharmaceutical manufacture for illnesses contracted by people in rich societies may make investment in discovering or inventing good ideas worthwhile in spite of the prospects of unremunerated dissemination.

Although designing extremely low-cost provision of electrical power may lack some of the features that make investment attractive despite the risk of intellectual property theft, it also has potential benefits that innovation in military or health-care technologies lack. In particular, it enhances productivity in provision of almost every good or service an economy trades in. It would also solve the actual owner's climate change problem, a benefit not limited or reduced in value by the provision of the same benefit to everyone else. It was considerations similar to these that prompted the international sharing of COVID-19 vaccines.

There are thus circumstances in which it would be rational for individuals, coalitions, corporations, or even nation-states to seek such a technology. Once hit upon, the incentives for others to acquire and employ it could be harnessed to slow, stop, or even roll back the public harm of increased world temperatures. How quickly any of these three outcomes might emerge would depend entirely on the rate of technological conversion of energy sources. To make this rate rapid, the costs to individual corporations of conversion will have to be so low that owners of current higher-cost energy sources will be unable to slow conversion by offering their technology and conventional inputs at concessionary prices or by threatening consumers with military or other consequences to prevent purchase from cheaper sources.

This solution to the climate crisis is a free-market, laissez-faire capitalism prescription that harnesses incentives already in place and requires no additional constraints to shift behavior away from individual perceived self-interest. An obvious possible technology that has features that would make possible this free market solution to the problem of climate change is hydrogen fusion. If ever made into a feasible source of energy, its use would produce a substantial short-term, first-mover benefit to the corporation or nation that hits upon it. What is more, if the costs of climate change to the country or corporation that invents fusion technology are great enough, it will have an incentive to share the technology widely so as to mitigate climate damage to itself. Indeed, coalitions of other nations facing catastrophic climate change costs would have strong incentives to use force to secure the technology, even if its owners decline to provide it to others or decline to do so quickly enough.

On the other hand, the scientific barriers to fusion and the track record of surmounting any of them make the commercial investment in fusion technology look irrational even to the most risk-prone entrepreneur. Like all scientific discoveries, fusion power is a matter or radical uncertainty, not well-behaved probability. The only rational incentive for undertaking the research required is the prospect of scientific immortality. Investment in the development of fusion technology largely substantiates these conclusions from simple game theory and public choice economics.

There is, of course, some investment and research that has been and continues to be undertaken by governments and corporations (usually with government support) to develop fusion technology. It is difficult to say whether it has made significant advances. Proponents have argued for about fifty years that fusion power is "just ten years" away, but given the potential benefits, the amount of investment does not seem large. There are about twenty research programs involving thirty firms worldwide that aim at about five or six different approaches to fusion power. Of those disclosing financing sources, the total investment approaches 2.4 billion USD.[40] Investors include the usual suspects among the world's wealthiest individuals, especially with some independent interest in theoretical science and a willingness to act in the face of Knightian uncertainty.[41]

In 2018 the U.S. Department of Energy commissioned a panel to advise it on fusion research investment and priorities. This body was composed mainly of research scientists working in government national laboratories or in universities supported by the National Science Foundation and the Department of Energy. As public choice theory leads one to expect, this body attached great (perhaps greatest) weight to the pure science of fusion energy production as the target of research for U.S. national fusion policy. Their report identifies distinct areas of critical research needs that are largely matters of theoretical science: controling and predicting the dynamics of a burning plasma (a problem in plasma physics) and how the properties of materials evolve and degrade due to fusion neutron exposure (a problem in materials science). Lastly, it endorses the study of the engineering issues of designing plant equipment, remote handling, tritium breeding, and safety systems. The report offers three scenarios for future government support: the current level, a higher level exceeding inflation by 2 percent, and an "unconstrained" level at which fusion research would be given a great deal of additional funding. It prioritized research programs to be initiated at each level of funding; it did not endorse any of these three scenarios.[42]

VI. Conclusion

In the absence of detailed reliable data about payoffs, preferences, and the degree of common knowledge by the relevant agents, the tools of game theory are relatively blunt and predictively unreliable. It would be easy to put the reasoning of this essay into extensive-form and/or payoff-matrix models. Doing so might highlight in diagrams the available options and outcomes traced in this essay, but it would not improve the reliability of predictions made. Even without good data on payoffs and preferences, the game-theoretical considerations adduced here should help prepare us to deal with a likely bad or worst-case scenario over the next few centuries, one likely to be as great as the one humankind passed through 700 to 400 years ago. Solutions to the problem of climate change that rely on subverting state sovereignty, benevolent despots, or effective democratic decision-making

[40] Philip Ball, "The Chase for Fusion Energy," *Nature*, November 17, 2021, https://www.nature.com/immersive/d41586-021-03401-w/index.html.

[41] Frank Knight, *Risk, Uncertainty, and Profit* (Boston, MA: Houghton Mifflin Company, 1921).

[42] Stephen Binley, "Envisioning the Future of Fusion Energy and Plasma Research," *Energy.Gov*, February 18, 2021, https://www.energy.gov/science/articles/envisioning-future-fusion-energy-and-plasma-research, 6-7.

by enlightened, disinterested voters, are nonstarters. If the only solution is a good idea that will bring material reward to its discoverer or inventor, then everyone ought to invite, support, and reward entrepreneurial agents to invest in their production.

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