Catastrophe and Climate

Effects of Pollution and Environmental Degradation on Mortality and Morbidity Rates and Healthcare Costs

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Executive Summary

Human health is largely dependent on environmental health. As our environment degrades, human mortality and morbidity is also degrading. Can the increased costs associated with environmentally induced life and health effects be measured? Global organizations and researchers are endeavoring to do just that, but the estimates are far from all-encompassing and notably understated. Clearly, any changes in mortality and morbidity have an insurance implication. Should actuaries be considering environmental impacts when pricing their products? Which subsets of the population might be affected? Could there be a workers' compensation impact? Although quantification may be difficult, understanding the potential effects of various environmental changes on mortality and morbidity is the obvious starting point for actuaries. Awareness is the critical first step.

Introduction

Scientific study has clearly demonstrated a link between the degradation of our natural environment and increased mortality and morbidity within the human population. This increase in mortality and morbidity incurs various costs, including financial costs. The quantification of these costs is useful to public health officials and regulatory agencies in developing resource allocation and prioritization strategies and in cost/benefit analysis. For example, the likely scope of disease and dysfunction associated with industrial chemicals will inform decisions on their use and manufacture. Since actuaries are tasked with estimating costs associated with health and lifespan, we too, need to understand the components of the costs incurred through environmental degradation and how they may be changing over time.

Natural capital quantification, in which ecosystem services or natural capital are assigned concrete monetary value, is an approach that is commonly used to guide sustainability policy. For example, the value of an acre of forest might be determined based on the timber it might produce; the fruit, nuts or other products that could be gathered from it; the carbon it might store; the soil erosion it might hinder; the game species it might harbor; the rare or non-game species it might support; the oxygen it might produce; the water it or the soil held in place might filter; the floods it may absorb; the windbreak it might create; etc. The list goes on, illustrating the complexity of the quantifying task. This process is fraught with difficulty. Natural capital often has irreplaceable or unique features. Natural systems are multifunctional. How does the value change due to loss of one of many functions? Valuation is challenging. Wages and incomes are sensitive to geography and time. Time horizons matter. There are missing and unobtainable values. Unsurprisingly, there is a bias toward more easily priced services. (Cole 2019)

This article seeks not to price all ecosystem services but to understand and begin to quantify the functions that promote human health through the increased morbidity and mortality cost in the face of environmental degradation. Since ecosystem services contribute toward a healthy human population, any morbidity or mortality cost from the effects of environmental degradation represent a loss of ecosystem services. Going back to our forest example, it is relevant to consider how much the forest contributes to human health or how much human health would suffer if that forest were lost. These costs can be quantified by a method analogous to natural capital, the human capital approach. The human capital approach is based on the sum of direct costs from medical treatment and indirect costs such as output lost due to illness (lost earnings, lost productivity).

Environmental degradation affects so much of human health, from the air we breathe to the food we eat to the water we drink, that covering all the effects on morbidity and mortality could fill several volumes. Here, we touch on the most pervasive impacts and the costliest related diseases.

The Effect of Environmental Degradation on the Insurance Industry

Unexpected changes in the burden of disease affect many types of insurance. The increased risk may be masked by medical advances in the same or other diseases. Nonetheless, increasing ill health due to environmental degradation will show up on the radar either through increased costs or mortality. Knowing the causes and the populations most at risk, be it spatially, age, or otherwise will help actuaries more accurately estimate insurance loss costs.

Obviously, increased health care costs will greatly affect health insurance, but health insurance benefits are generally annual policies that cover care within a short-tailed policy period. As such, increased health costs will naturally be incorporated into the pricing structure, even if the cause is unacknowledged. Other, longer tailed, policies- either on the care or the occurrence side- may have a greater stake in estimating and interpreting cost effects from environmental ills and how they may be accelerating.

Though workers compensation only covers occurrences within typically annual policy periods, the care related to the occurrence is covered indefinitely. Additionally, the coverage is statutory with a lag time between changes in medical knowledge and regulation. Understanding the effects of environmental degradation on diseases and on recovery time can aid in successful pricing. Understanding causes is important since some environmental degradation (particulate or chemical exposure, for example) has historically been more concentrated in the workers of particular industries.

Long-term care insurance is complex. Decreasing health due to environmental degradation would increase necessary premiums to the extent that it increases the time or amount of care. Depending on the wait time to increase premiums, unanticipated change could harm a company. Additionally, a change in lapse rates due to the insureds being cognizant of the increased risk of ill health before the insurers may decrease profits. If policies were priced assuming higher lapse rates than experienced, the lack of expected reserve release would lead to higher-than-expected reserve levels.

Life insurers typically make assumptions about lifespan increase due to healthcare improvement. Acceleration of environmental degradation could indicate a declining rate of increase in life span rather than the expected flat percentage increase. Recognizing this in a timely manner is important. For example, universal life policies can have their cost of insurance (COI) increased up to the guaranteed COI, but the change must first be recognized. Life insurers often hedge (whether implicitly or explicitly) their mortality risk through defined benefit pension coverage. Assuming a hedge is a risky assumption which works for certain only if the same lives are part of both the life and pension plans. Otherwise, though long-term there may be some balance, on an annual basis there is not necessarily a strong negative correlation in results. If the underlying environmental degradation is pervasive, there may be more of a balance between the coverages, but if the degradation is spatially, temporally, or otherwise uneven, the relative populations may cause a short term imbalance between the coverages.

Increasing Rate of Environmental Degradation

The "Anthropocene" is defined as the period of time in which human activity has had more of an impact on earth than natural events. As human activity increases, human life span and health is affected. The Anthropocene includes the great acceleration from the mid-20th century until the present during which the rate of environmental change began to increase exponentially. Anthropogenic factors include atmospheric concentrations of carbon dioxide (CO_2), nitrogen oxides (NO_X) including nitrous oxide (N_2O), methane (CH_4), and ozone (O_3); ocean acidification; tropical forest loss; water and fertilizer use (Cole, 2019). The number and quantity of man-made chemicals that are being produced has accelerated (Duncan, 2019). Exploration, mining, and processing of minerals has also accelerated through the 20th century and into the present. During the Anthropocene, radiation from wartime and cold-war weapons use and testing as well as nuclear power and increased X-Ray and other medical radiation grew exponentially. To consider some of the impacts of these accelerations on morbidity and mortality costs, we first need to devise a method of cost valuation.

Valuation of Morbidity/Mortality Costs

The largest systematic, data-driven effort to quantify health loss from all major diseases and injuries on a world-wide scale is the Global Burden of Disease study coordinated by the Institute for Health Metrics and Evaluation (IHME). The global burden of disease study aims to quantify the burden of premature mortality and disability for major diseases using a summary measure of population health, referred to as the disability-adjusted life years (DALY). The DALY considers all factors, not just environmental, but it includes subtotals for individual environmental health factors. The DALY includes potential years of life lost due to premature death and equivalent years of 'healthy' life lost by illness or disability; it combines mortality and morbidity into a single metric.

A similar measure is Quality-adjusted life years (QALY). QALY is subjective, based on perceived willingness to accept different states of health. It is often used in the evaluation of medical interventions and combines both the quality and the quantity of life lived; it ranges from one, perfect health, to 0, dead.

DALYs and QALYs are related, but QALYs tend to be an individual measure, while DALYs can be societal. DALYs can be time and/or age weighted. Age-weighted DALYs consider years lost at different ages differently while time weighted DALYs discount future years lost. Whether calculations are time or age weighted is not always transparent and differs from study to study and year to year making comparisons difficult.

The World Health Organization (WHO) also produces an environmental cost of disease estimate. The WHO and IHME estimates are based on differing risk factors. The global annual cost for the groups of diseases selected by the WHO experts was $4 trillion (equates to 260 million DALYs) while the IHME's estimate was 127 million DALYs (Shaffer et al. 2019). There is very little overlap in the risk factors considered by the IHME and the WHO, indicating that the total environmental burden of disease would likely be substantially greater than either of their calculations. The total environmental burden of disease costs likely exceeds 10% of the global Gross Domestic Product (GDP) (Granjean and Bellanger, 2017).

Recent work has indicated that the typical DALY calculation underestimates the total burden of disease since it disregards subclinical dysfunctions, adheres to stringent causal criteria, and requires more complete data than is often available. When there is incomplete or insufficient data, an estimate of $0 cost is often used, which is generally a large understatement (Granjean and Bellanger, 2017). IHME's global burden of disease estimates capture only limited risk factors for environmental health including only certain air pollutants, water, lead, and occupational exposure (Shaffer et al. 2019) while disregarding other developmental neurotoxicants such as pesticides, methylmercury, and arsenic, and other effects of air pollution such as preterm birth and brain development. In addition, information in some geographic areas is more limited than others. The U.S. and the EU have more complete data; therefore, we will reference several calculations limited to the U.S. and the EU. These cannot necessarily be extrapolated worldwide since local conditions vary.

Researchers have been working on more complete measures of health impacts from environmental degradation than are currently provided in the IHME and the WHO estimates. For example, Grandjean and Bellanger (2017) take a toxicology-based health economics approach using assessments of environmental chemical exposures in combination with the economic value of environmentally related adverse health outcomes. They attribute disease burdens to environmental exposures by

$$\text{Disease burden} = \text{Disease rate} * \text{AF} * \text{Population size}$$

where AF is "Attributable Fraction"; the percentage of a particular disease category that would be eliminated if the environmental risk factor were reduced to its lowest feasible level.

The IHME's Global Burden of Disease-Pollution and Health Initiative (GBD-PHI) aims to improve the estimates of burden of disease attributable to environmental health factors. The GBD-PHI suggests research priorities and factors for incorporation into upcoming iterations of the global burden of disease study. They note many missing impacts, effects and environmental health risk factors (Shaffer et al. 2019).

The human capital approach to estimation has important advantages over DALYs since it is transparent and allows assessment of costs associated with subclinical dysfunctions that may occur without a formal medical diagnosis or treatment. Limiting to a formal medical diagnosis can miss important costs.

There are many ways that economic cost for individual environmental maladies is being measured. Often, organizations measure economic costs for constrained geographic areas. It could be worthwhile for an actuary to investigate potential environmental cost measures associated with smaller regions, when pricing products in specific areas.

Diseases

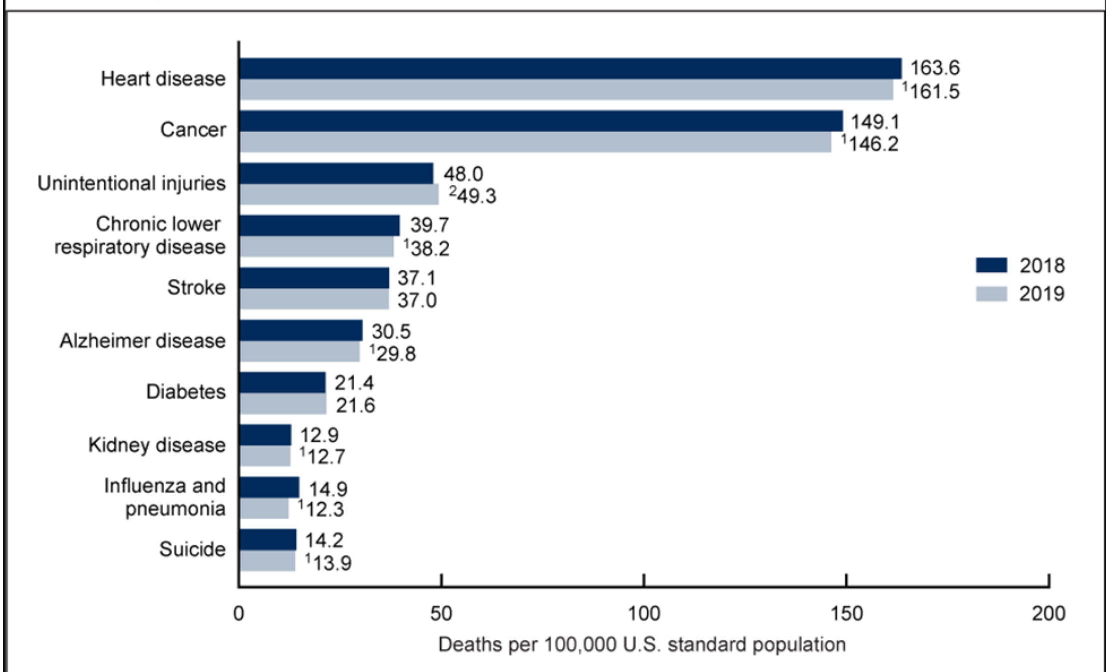
COSTLIEST DISEASES AND PERCENT OF COSTS ATTRIBUTABLE TO ENVIRONMENT

Many of the costliest diseases in the U.S. and Canada are caused or exacerbated by environmental degradation; heart disease, cancer, lung diseases (chronic lower respiratory disease, chronic obstructive pulmonary disease), stroke, Alzheimer's disease/dementia, diabetes, kidney disease, premature birth, influenza, and pneumonia all are negatively affected by environmental degradation. Without consideration of environmental factors, the 10 leading causes of death in the United States are shown below.

Figure 1

10 LEADING CAUSES OF DEATH IN THE U.S.

Figure 4. Age-adjusted death rates for the 10 leading causes of death in 2019: United States, 2018 and 2019



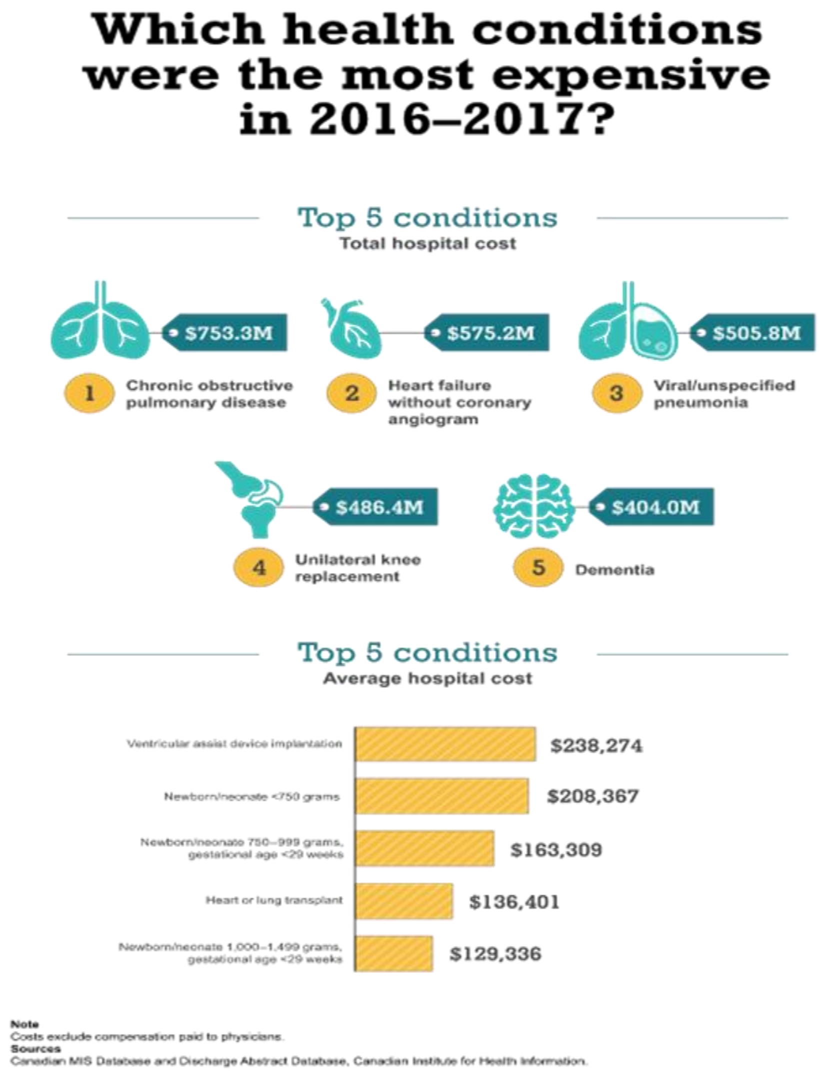
[1]Statistically significant decrease in age-adjusted death rate from 2018 to 2019 ($p < 0.05$).
[2]Statistically significant increase in age-adjusted death rate from 2018 to 2019 ($p < 0.05$).
NOTES: A total of 2,854,838 resident deaths were registered in the United States in 2019. The 10 leading causes of death accounted for 73.4% of all deaths in the United States in 2019. Causes of death are ranked according to number of deaths. Rankings for 2018 data are not shown. Data table for Figure 4 includes the number of deaths for leading causes. Access data table for Figure 4 at: https://www.cdc.gov/nchs/data/databriefs/db395-tables-508.pdf#4.
SOURCE: National Center for Health Statistics, National Vital Statistics System, Mortality.

Products - Data Briefs - Number 395 - December 2020 (cdc.gov) db395-fig4.png (960×720) (cdc.gov)

In this next chart, Canada lists the most expensive health conditions on a total population basis and on an average hospital cost basis.

Figure 2

MOST EXPENSIVE HEALTH CONDITIONS IN CANADA

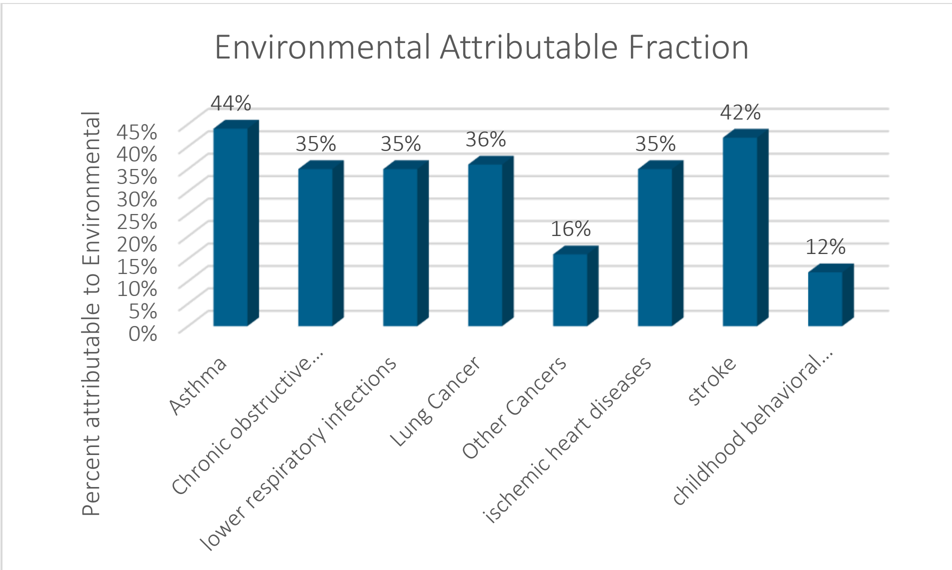


https://www.cihi.ca/en/which-health-conditions-are-the-most-expensive (Canadian Institute for Health Information)

Many of the most deadly and costly diseases are linked closely to a particular chemical or pollutant. For example, premature births and still births, both Type 2 and Type 1 diabetes are all linked to endocrine disrupting chemicals (EDCs). Heart disease is linked to EDCs through insulin resistance. (DiCiaula and Portincasa, 2021) Our highly-processed and factory-farm produced diet has an enormous impact on cancer (second only to that of smoking in developed societies according to Greaves as related by Cole, 2019).

The chart below notes the environmental attributable fractions according to WHO experts for a range of relevant diagnoses. We see that over 40% of strokes and asthma and over 35% of chronic obstructive pulmonary disease, lower respiratory infections, lung cancer and ischemic heart diseases are attributable to environmental chemical exposure. 15% of other cancer and 12% of childhood behavioral neuropsychiatric disorders are also attributable to environmental chemical exposure (Grandjean and Bellanger, 2017). These are some of the most expensive and deadly health conditions and they contribute heavily to the burden of disease.

Figure 3
ENVIRONMENTAL ATTRIBUTABLE FRACTION OF DISEASE COST



Based on attributable risks derived by WHO as given in Granjean and Bellanger (2017)

LESS COSTLY, BUT MORE WIDESPREAD DISEASES

While many of the most expensive diseases with a large environmental component of cause can be costly on an individual basis, some less severe afflictions can be costly on a cumulative basis. There could be a significant increased cost due to frequency rather than severity. That is, increased cost due to frequency can be just as costly as that due to severity. Some diseases may be easily treated with an excellent prognosis but may require continued care with long-term use of medications. In some cases, individuals who were self-medicators using over the counter medicines, may escalate to physician care, which would increase the known health care population. Allergies and obesity both fall into this group. For individuals already known to the healthcare system, there would be an increase in healthcare use.

Thyroid problems have been linked to Endocrine Disrupting Chemicals (EDCs) as have obesity in adults and pediatric cases (DiCiaula and Portincasa, 2021). EDCs have also been implicated in low semen quality (reduction in sperm count, impaired sperm motility, abnormal sperm cells), genital malformations in males, and altered reproductive function in females (DiCiaula and Portincasa, 2021). Increased rates of autism and ADHD are tightly correlated to EDC exposure and EDCs have proven to contribute to both these maladies.

Climate change triggers spatial and temporal shifts in plant airborne pollen loads leading to major health consequences in the form of allergies, asthma, viral infections, school performance and emergency room visits. Long-term pollen data from the National Allergy Bureau from 60 North American stations from 1990 to 2018 indicate widespread advances and lengthening of pollen seasons (+20 days) and increases in pollen concentrations (+21%) across North America which are strongly linked to increasing temperature (Anderegg et al. 2021). The largest increases were in Texas and the midwestern United States. Tree pollen showed the largest increases in spring and annual integrals. The pollen season start date moved forward and the season lengthened. Pollen is an important trigger for many allergy and asthma sufferers and pollen concentrations are strongly linked to medication purchases, emergency hospital visits, susceptibility to viral infections through exacerbating respiratory inflammation and weakened immune response which will likely lead to higher associated medical costs (Anderegg et al. 2021).

Main Environmental Drivers of Morbidity/Mortality

AMBIENT AIR POLLUTION

Outdoor air pollution is an enormous problem. The WHO designates air pollution as the largest environmental risk factor (WHO 2016). Globally, air pollution is estimated to cause 7 million premature deaths (Gardiner p. 4) and cost over $5 trillion annually. In the United States it causes over 200,000 premature deaths annually (Gardiner p. 266). Over 40% of Americans breath unhealthy levels of pollution (Gardiner p. 4). Air pollution exacerbates asthma, bronchitis, heart attacks, strokes, birth defects, cancer, dementia, other cognitive decline, diabetes, Parkinson’s, premature birth, and mental illnesses such as depression (Gardiner p. 4, 21).

Air pollution is a general term including many and varying ingredients which induce a myriad of health effects. Often, health issues and multiple chemicals combine to worsen the effects. Major air pollutants according to the U.S. Environmental Protection Agency (EPA) - are carbon monoxide (CO), lead (Pb), particulate matter (PM), nitrogen dioxide (NO_2), ozone(O_3), and sulfur dioxide (SO_2), (together the six “criteria pollutants”), air toxics (multiple chemicals), and stratospheric ozone-depleting chemicals. Particulate matter air pollution may include copper, tungsten, lead, carbon, silicon, iron, aluminum, titanium, and sulfur (Gardiner p. 35). There are both natural and anthropogenic components to air pollution. The main causes of air pollution are transportation, heat and power generation, industrial facilities (manufacturing factories, mines, oil refineries), industrial agriculture, and natural disasters such as wildfires. (EPA 2021)

A study on the economic impact of the US Clean Air Act found that 20 years after the clean air act was passed particle pollution was 45 percent lower while SO_2 had decreased 40 percent, NO_2, 30%, and airborne Pb had decreased 99% (Tables 1 and 2) with combined benefits of $22 trillion (44 times the cost of complying with the regulations) (Gardiner p. 153). In just one year (1990) the clean air act saved 200,000 lives and averted 150,000 hospitalizations for heart and lung troubles (Gardiner p. 153). This data shows the importance of these types of legislative changes. Global changes are more difficult to enact, but efforts are being made. It’s also important to be aware of changes to enacted legislation that may loosen the regulations leading to an increase in costs.

Table 1

PERCENT CHANGE IN EMISSIONS OVER TIME

	1980 vs 2019	1990 vs 2019	2000 vs 2019	2010 vs 2019
Carbon Monoxide	-75	-69	-56	-27
Lead	-99	-87	-76	-30
Nitrogen Oxides (NOx)	-68	-65	-61	-41
Volatile Organic Compounds (VOC)	-59	-47	-27	-18
Direct PM10	-63	-30	-27	-17
Direct PM2.5	---	-36	-43	-20
Sulfur Dioxide	-92	-91	-88	-73

https://www.epa.gov/air-trends/air-quality-national-summary

Table 2
PERCENT CHANGE IN AIR QUALITY OVER TIME

	1980 vs 2019	1990 vs 2019	2000 vs 2019	2010 vs 2019
Carbon Monoxide	-85	-78	-65	-23
Lead	-98	-98	-93	-85
Nitrogen Dioxide (annual)	-65	-59	-51	-25
Nitrogen Dioxide (1-hour)	-62	-51	-36	-17
Ozone (8-hour)	-35	-25	-21	-10
PM10 (24-hour)	---	-46	-46	-17
PM2.5 (annual)	---	---	-43	-23
PM2.5 (24-hour)	---	---	-44	-21
Sulfur Dioxide (1-hour)	-92	-90	-82	-71

https://www.epa.gov/air-trends/air-quality-national-summary

Though air quality has improved dramatically in the U.S. since the clean air act in 1970, many are still negatively affected by air pollution (Air Quality - National Summary | National Air Quality: Status and Trends of Key Air Pollutants | US EPA). The burning of fossil fuels causes 10.2 million premature deaths in North America annually. Excess annual deaths due to Lower Respiratory infections in children under 5 is 876 in North America (Vohra et al 2021).

There are many types of air pollution and many areas plagued by air pollution have confounding factors making estimates of associated health costs difficult. However, it has been shown that even typical air pollution such as that from roads has a significant health cost. Effects on pregnancy and children may be most expensive. Underweight babies and premature births are 10 percent more common born of women living near heavy traffic. Extremely premature births are 80 percent more likely. Risks of pre-eclampsia, miscarriage and infertility have also been linked to air pollution (Gardiner p. 24) as have problems with the children after birth such as SIDS, heart malformation, autism, pediatric leukemia, kidney cancer, eye tumors and malformations of ovaries or testes (Gardiner p. 26).

Nature interacts with man-made pollution, increasing costs. For example, in Los Angeles, California the sun triggers chemical reaction to unburned fuel and NO_X to interact and form ozone (Gardiner, p. 197) which is more detrimental to health than the components alone.

It is estimated that agriculture causes half of the man-made air pollution in America and 55 percent in Europe. In many areas it is the largest single cause of air pollution-linked deaths (Gardiner p. 112). Concentrated animal feeding operations (CAFOs) cause large amounts of air pollution. The operations exude methane and ammonia which combine with NO_x from vehicles servicing the CAFOs and create $PM_{2.5}$. Manure dust is another irritant. The volatile organic compounds put off by the silage combine with NO_x into ozone which is toxic to humans at ground level (Gardiner chp. 5). Premature births, asthma and migraines are some results of this. A study in California's central valley- an area with extreme pollution problems due to CAFOs combined with fracking and oil drilling- found the economic cost of air pollution to be $6 billion a year ($1,600 per resident) (Gardiner p. 117).

Transportation is another top polluter and various modes of transportation have varying effects on health through air pollution. Diesel exhaust contains more NO_x than exhaust from gasoline (Gardiner p. 73) and as the diesel scandal demonstrates, costs may be higher than anticipated. The diesel scandal developed when it was found that 97% of more than 250 automobile models were in violation of the regulatory laws of the countries in which they were emitting (either the US or in Europe). It started when VW was found to have modified its vehicle software to comply with emissions standards only when being tested and not during normal driving. One study estimated 6,800 early deaths in 2015 alone from failure to comply with the rules (Gardiner p. 182). Also, different grades of fuel vary in emissions. Bunker fuel used for international shipping, for example, contains up to 1,800 times more sulfur than allowed in land-based vehicle fuel. Pollution from cargo ships is estimated to be responsible for 50,000 deaths in Europe each year (Gardiner p. 207). The ports of LA and Long Beach are Southern California's single biggest source of air pollution (Gardiner p. 210)

Though public transportation is better in terms of air pollution per person transported than individual vehicles, this does not necessarily insulate riders of public transportation from the negative effects of air pollution. The $PM_{2.5}$ concentrations in subway systems during rush hour in the Northeastern United States are far above the nationally determined safe daily levels of 12 micrograms per cubic meter. Unhealthy levels are defined as 35.4 micrograms per cubic meter for a 24-hour concentration. The all system mean underground $PM_{2.5}$ was 362 with PATH in NYC having the highest mean of 779 micrograms per cubic meter (Luglio et al. 2021). $PM_{2.5}$ in subways typically contains iron, copper, and manganese generated by the interaction of the train's electrical current collector shoe with the supply rail. In addition, though passenger trains are typically electric, the maintenance machinery is typically diesel.

The increasing number of wildfires is adding to air pollution. Wildfire smoke often contains carbon monoxide (CO), NO_X, benzine, cresols, biphenyl, hydrogen cyanide, naphthalene and polycyclic aromatic hydrocarbons, and of course $PM_{2.5}$. Wildfire smoke contains not only the natural chemicals trees produce, but also those from pesticides, fertilizers, prior air and water pollution that had been taken up in the trees of on the forest floor, and the contents of any burned buildings.

Most estimates of air pollution harm are underestimated. With regard to ambient air pollution, the IHME calculations include particulate matter and ozone totaling 74.7 DALYs or $1.1 trillion annually, while the WHO estimate for particulate matter is 85 DALYs or $1.2 trillion. Both focus on pulmonary disease, lung cancer, and cardiovascular effects. The IHME ignored preterm birth or low birth weight linked to $PM_{2.5}$ exposure in utero which led not only to direct medical care costs for the neonate, but also lifelong costs due to ongoing medical care and lowered IQ. Additional cognitive deficits have been linked to air pollution exposure prenatally and through school age. Asbestos is another ambient air pollutant, but IHME includes it only for occupational risk. Asbestos and other substances listed by the IHME as occupational hazards likely contribute to community risk which may be heightened for children. The WHO, likewise, ignored effects outside of pulmonary disease, lung cancer and cardiovascular. (Grandjean and Bellanger, 2017) (See Table 3)

Though North America has fairly good air quality compared to much of the world, we do have many immigrants and residents from countries with the worst air quality. India, for example, contains 14 of the top 20 most polluted cities (and 6 of top 10, 21 of the top 30). China contains 14 of the most polluted 24 non-Indian cities (IQAIR 2019). Since air quality has long-lasting effects (for example on the decreased lung capacity and health of those who, as children, breathed heavy air pollution) world air quality and prior air quality may affect the US and Canadian markets more than our current air quality alone would suggest.

ENVIRONMENTAL CHEMICAL EXPOSURES

The disease burden associated with environmental chemical exposures has been estimated by various methods. The total cost estimated for specific risk factors with known toxicology and exposure data indicate a cost over $716 billion per year in the U.S. and over $533 billion in the EU (2010 US$) which equates to 4.78% of GDP for the U.S. and 3.67% of GDP for the EU. The estimate for the world was 5.3% of GDP (Grandjean and Bellanger,2017) (Table 3) An estimate based on the attributable fractions for attributable risks derived by WHO indicates 6.5% of Global GDP and a cost of $4.05 trillion. The IHME authors indicate over 3%. The risk factors considered by the three different approaches only partially overlap and thus the total environmental burden of disease costs likely exceed 10% of Global GDP. Even this estimate is not complete.

NEUROTOXICANTS

There are many environmental chemicals that cause harm. The estimates in table 3, below, based on data from Grandjean and Bellanger (2017), include only a portion of them. Regarding neurotoxicants- chemicals that cause adverse effects in the nervous system and sense organs - the IHME calculation focuses mainly on lead, and only considers costs for those children whose cognitive function moves into the subnormal range, not those whose lead exposure lowers their function within the normal range which leads to an underestimate of cost. As you see below, Grandjean and Bellanger (2017) broaden their analysis to include other neurotoxicants such as methylmercury, often found in fish downstream of dams; organophosphate pesticides, linked to IQ deficits; and polybrominated diphenyl ethers, chemical flame retardants linked to IQ deficits. All of the chemicals considered are also associated with exposure-related increases in ADHD and autism, but only cognitive deficit costs are included in any of the estimates. The four neurotoxicants listed, which contribute costs more than 2.5% of GDP, are part of a group of 12 convincingly associated with adverse effects on human brain development. The other eight may be just as significant but could not be reasonably estimated due to insufficient exposure documentation and, in some cases uncertain dose-response relationships especially at low exposure levels. Arsenic costs alone may be at a similar magnitude to lead. (Grandjean and Bellanger, 2017) The neurotoxicants costs in all major estimates only reflect intellectual disabilities and not less severe cognitive dysfunctions, leading them to substantially underestimate the total societal costs due to neurotoxicity.

Table 3

DISEASE BURDEN ASSOCIATED WITH ENVIRONMENTAL CHEMICAL EXPOSURES

Group of risk factors	Risk Factor	Adverse Consequences	Place	Economic Cost per year (US$millions)	% GDP
neurotoxicants	Lead exposure	cognitive deficits	U.S.	54,000	0.37
neurotoxicants	Lead exposure	cognitive deficits	EU	60,600	0.36
neurotoxicants	Methylmercury	cognitive deficits	U.S.	4,800	0.03
neurotoxicants	Methylmercury	cognitive deficits	EU	10,800	0.06
neurotoxicants	organophosphate pesticides	cognitive deficits	U.S.	44,700	0.3
neurotoxicants	organophosphate pesticides	cognitive deficits	EU	194,000	1.14
neurotoxicants	polybrominated diphenyl ethers	cognitive deficits	U.S.	266,000	1.8
neurotoxicants	polybrominated diphenyl ethers	cognitive deficits	EU	12,600	0.07
various	Air Pollution	Asthma	U.S.	2,330	0.02
various	Air Pollution	Asthma	EU	1,700	0.01
various	Air Pollution	Preterm birth	U.S.	4,300	0.01
various	Air Pollution	Cardiovascular	EU	37,240	0.22
various	Air Pollution	All heath impacts	OECD	500,000	1.2
various	Air Pollution	All heath impacts	China	483,000	8
various	Air Pollution	All heath impacts	India	120,000	7
Endocrine disruptors	polybrominated diphenyl ethers (PBDs)	Testicular cancer	U.S.	81.5	0.01
Endocrine disruptors	polybrominated diphenyl ethers (PBDs)	Testicular cancer	EU	1,100	0.01
Endocrine disruptors	polybrominated diphenyl ethers (PBDs)	Cryptorchidism	U.S.	35.7	0.01
Endocrine disruptors	polybrominated diphenyl ethers (PBDs)	Cryptorchidism	EU	172.6	0.01
Endocrine disruptors	dichlorodiphenyl trichloroethane (DDE)	Childhood obesity	U.S.	29.6	0.01
Endocrine disruptors	dichlorodiphenyl trichloroethane (DDE)	Childhood obesity	EU	32.7	0.01
Endocrine disruptors	dichlorodiphenyl trichloroethane (DDE)	adult diabetes	U.S.	1,800	0.01
Endocrine disruptors	dichlorodiphenyl trichloroethane (DDE)	adult diabetes	EU	1,100	0.01
Endocrine disruptors	dichlorodiphenyl trichloroethane (DDE)	Fibroids	U.S.	259	0.01

Endocrine disruptors	dichlorodiphenyl trichloroethane (DDE)	Fibroids	EU	216.8	0.01
Endocrine disruptors	Di-2ethylhexyl phthalate	Adult obesity	U.S.	1,700	0.01 1
Endocrine disruptors	Di-2ethylhexyl phthalate	Adult obesity	EU	20,800	0.12
Endocrine disruptors	Di-2ethylhexyl phthalate	adult diabetes	U.S.	91.4	0.01
Endocrine disruptors	Di-2ethylhexyl phthalate	adult diabetes	EU	807.2	0.01
Endocrine disruptors	Di-2ethylhexyl phthalate	Endometeriosis	U.S.	47,000	0.32
Endocrine disruptors	Di-2ethylhexyl phthalate	Endometeriosis	EU	17,00	0.01
Endocrine disruptors	Bisphenol A	Childhood obesity	U.S.	2,400	0.02
Endocrine disruptors	Bisphenol A	Childhood obesity	EU	20,000	0.02
Endocrine disruptors	Benzyphtalates & butylphalates	Matle infertility increases ART	U.S.	2,500	0.02
Endocrine disruptors	Benzyphtalates & butylphalates	Matle infertility increases ART	EU	6,300	0.04
Endocrine disruptors	Phtalates	low testosterone, increased mortality	U.S.	8,800	0.06
Endocrine disruptors	Phtalates	low testosterone, increased mortality	EU	10,600	0.05
Endocrine disruptors	Multiple exposures	ADHD	U.S.	698	0.01
Endocrine disruptors	Multiple exposures	ADHD	EU	3,056	0.01 4
Endocrine disruptors	Multiple exposures	Autism	U.S.	1,984	0.01 4
Endocrine disruptors	Multiple exposures	Autism	EU	352	0.01
Endocrine disruptors	All Compounds		U.S.	340,000	2.33
Endocrine disruptors	All Compounds		EU	217,000	1.2
		All listed	U.S.	783,509	5.38
			EU	600,177	3.38

Data from Granjean and Bellanger tables 1 ,2, 3 (2017)

ENDOCRINE DISRUPTING CHEMICALS

Endocrine disruptors lead to a variety of diseases and dysfunctions. They have been linked to cognitive dysfunction, childhood and adult obesity, testicular cancer, male infertility and mortality associated with reduced testosterone, fibroids, and endometriosis, none of which are usually included in burden of disease calculations. The section on Endocrine disruptors in Table 3 details the outcome of calculations wherein the costs for EDC exposures in the US and EU are $340 and $217 billion respectively. These are minimum estimates since the calculations include only substances and outcomes for which exposure data were available and which have a high probability of causation. Other diseases or chemicals which are known to be associated with adverse health effects are not included in the GBD or other estimates.

RADIATION

Exposure to radiation has increased greatly since WWII due to war, cold war, nuclear power (including accidents therefrom) and increased medical use. Long-term low-dose radiation exposure on a healthy individual leads to decline of immune system. Nuclear weapons testing exploded the equivalent of 29,000 Hiroshima-sized bombs between 1945 and 1998 (Brown 2019). Low-dose radiation from US nuclear testing in Nevada from 1951-1962 was strongly associated with cancer mortality rates in Iowa, Illinois, Kansas, Missouri, and Nebraska. Age-adjusted cancer mortality rates for many cancers (connective and soft-tissue sarcoma, thymus, female lymphosarcoma, colon, brain, thyroid, and uterine) were significantly correlated with total fallout and total precipitation. (Peterson and Miller, 2008)

More relevant than cancer fatality may be disease incidence and the probability of causation. Many individuals exposed in childhood during the 1950s to nuclear fallout Iodine 131(131I) absorbed doses equivalent to atomic veterans and radiation workers at Department of Energy sites who would qualify for compensation and medical care from the US government. A 95% confidence interval estimate of thyroid cancer from exposure to only the Nevada Test Sites ranges from 11,000 to 220,000 excess cases of thyroid cancer due to the 131I (Hoffman et al. 2002). The total impact from exposure to multiple sources of contamination in weapons testing and production has not been fully evaluated.

Radiation from nuclear testing in Nevada floated eastward, settling on the plains and being incorporated into cows' milk which was sold to the public. The milk-drinking population of the U.S. received on average a collective dose of radioactive iodine similar to that of people living in Chernobyl contaminated areas American, Russian, Indian, Pakistani, and Chinese bombs contributed to the radioactive fallout from nuclear testing, more of which came down in areas with more precipitation. As a response thyroid cancer rates grew exponentially in the Northern Hemisphere. Childhood leukemia and other cancers increased in Europe, North America, and Australia. Sperm counts among men in North America, Europe, Australia, and New Zealand dropped 52% between 1973 and 2011 (Brown 2019).

Sadly, the Chernobyl disaster set up a natural experiment for radiation exposure. Although an effort was made to hide the effects of the disaster, it is clear that the disease and death toll was much higher than the official estimate. Cancers spiked. Most prevalent were lymphomas, leukemia, cancer of the thyroid and intestinal tract. Much of the ingestion of radiation was from food grown in contaminated soil. A KGB study of the area noted that long-term, internal exposures of low doses of radiation on formerly healthy individuals lead to a decline in immune system and pathological changes and illnesses. In 1986 the European Community established a permissible level of radiation in food -600Bq/kg -as an emergency measure in response to Chernobyl and never lowered it. In 2016 the EU more than doubled permissible level – currently 1,250 Bq/kg - with no public discussion. Chernobyl-contaminated produce is still traded worldwide. At the U.S. -Canada border, a truck was stopped with a "radiating mass" which they originally thought might be a dirty bomb but instead found berries from the Ukraine which were subsequently sold to American consumers. (Brown p. 305)

When projecting mortality and morbidity it behooves us to keep in mind the probable exposure of our populations. Those who as children were exposed to high levels of radiation may not have the same mortality and morbidity trajectory as prior cohorts, especially as they age.

INTERACTION AND ACCUMULATION OF POLLUTANTS

Chemicals in combination can cause adverse effects that would not be predicted based on separate exposures to concentrations of each of the individual components. Many safety evaluations rely on the additive model, wherein chemicals that share a common health endpoint are evaluated together (MDH 2021). If allowable "safe" levels do not contemplate interaction and/or accumulation, levels may not be appropriate. Adding additional chemicals may push those exposed past a tipping point into more severe health reactions.

ZOONOTIC DISEASES

Over 35 new infectious diseases have emerged in humans since 1980. In a list of 1,415 human pathogens, 61% are known to be zoonotic including HIV (from the human consumption of non-human primates); Ebola (from great apes hunted for food), and SARS-associated coronavirus (from small non-domestic carnivores). Diseases can also be transmitted from wild to domestic animals, causing economic damage (over $80 million) and sometimes leading to human health problems. Examples of such diseases include bovine spongiform encephalopathy, foot-and-mouth disease, avian influenza, and swine fever (Karesh et al. 2005). Most recently, we see wild-animal-to-human transmission with SARS-CoV and COVID-19, which are both thought to have jumped to humans from wild animal markets in China. As we all know too well due to our experience in 2020, pandemics, such as COVID-19, can have a great and sudden impact on mortality and morbidity. (Conroy et al, 2020)

EVOLUTION

Charles Darwin, Alfred Russel Wallace, and Gregor Mendel introduced us to the theory of evolution whereby biological populations change over successive generations due to heritable characteristics. Main known drivers of change are natural selection and genetic drift. Natural diversity of characteristics due to mutation and genetic recombination are the material on which natural selection or genetic drift acts. The theory of evolution is based on three observable facts: traits vary among individuals, different traits confer different rates of survival and reproduction, and traits can be passed from generation to generation. Evolution has an enormous impact on health care costs.

Most of us are aware of strains of bacteria that have evolved to become resistant to our commonly used antibiotics. Evolution to increase fitness in this way is natural and to be expected. It does, however, greatly increase our health-care costs as these antibiotic-resistant bacteria can no longer be treated with common antibiotics so new antibiotics must be found or produced and the bacteria being treated must be cultured to find out which antibiotic might kill the particular strain of bacteria in question. More than 2.8 million antibiotic-resistant infections occur in the United States each year and more than 35,000 deaths result (CDC, 2019). The CDC recognizes antibiotic resistance as an alarming threat (CDC 2019).

Vaccination is widely seen as a possible antidote to antibiotic resistance and people and animals are routinely vaccinated against bacterial and viral diseases. Resistance evolves in the bacteria and viruses that affects the efficacy of these vaccinations. It is possible that widespread vaccination drives evolution of a more dangerous virus; keeping the host alive through vaccination may allow more virulent viruses to evolve and survive (Monosson,2015). If this is the case, we may need to adjust our use of vaccines to limit the vaccination pressure on virus evolution.

Evolution is also increasing the difficulty and cost of treating cancer as some cancer cells have evolved chemotherapeutic resistance. Research is underway to reduce or prevent chemotherapeutic resistance. As chemotherapy is the backbone of treatment for many cancers, chemotherapeutic resistance often results in therapeutic failure and earlier death. With 1.7 million newly diagnosed cancer patients in the U.S. annually, an increasing death rate affects overall mortality. (Alfarouk et al. 2015)

Insectan pests have also developed resistance to our known remedies through evolution, increasing healthcare costs. Bedbugs are an example. Bedbug bites can become infected leading to healthcare costs. In addition, the lack of sleep brought on by a bedbug infestation may lead to exacerbation of underlying conditions such as pulmonary, respiratory, or insulin resistance issues. Blindness to these increasing risks can lead to underestimates of health-care loss costs.

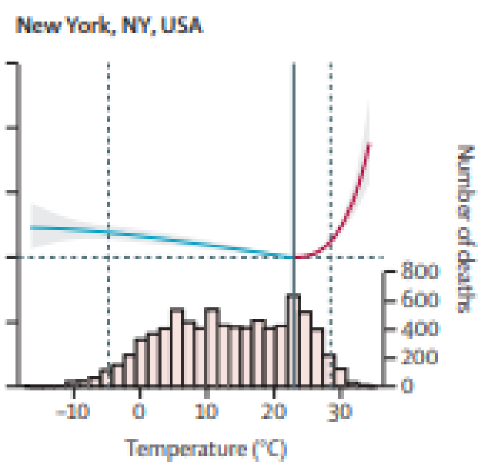
What, if anything, can insurers do to mitigate the increase in costs due to evolution? In the case of antibiotics, vaccines, and chemotherapy it is their use – or often overuse- that drives the evolution that leads to resistance. Antibiotics are not only useful in treating humans, but are also used in animals, on crops, and as growth promoters in livestock. Insurers could encourage responsible antibiotic stewardship by providing coverage and rates based on responsible use. Health insurers may be able to reduce use unnecessary use of antibiotics by limiting coverage for them. Agriculture or farm policy insurers may likewise be able to reduce their overuse. Along these lines, insurers could potentially slow resistance by viruses and cancer cells by managing healthcare on a larger scale. Such regulation, however, may be best done by a governmental body.

WEATHER AND NATURAL DISASTERS INCLUDING CLIMATE CHANGE

Climate change is now well documented. Average temperatures are rising, and the frequency and severity of natural disasters has been increasing. The connection between the natural disasters and mortality and morbidity is fairly obvious, but the connection with increasing temperatures may not be as clear.

Increased high temperature average, extremes and daily(nightly) lows will all affect mortality as will increased humidity. Gasparinni et al. 2015 found that the total fraction of deaths caused by temperature was 7.71% of all deaths in the countries covered. In North America, heat-related deaths have increased recently while cold related deaths have decreased. Overall, we see that, though there are more deaths in North America from cold than from heat, most of the cold-temperature-related mortality was from milder but non-optimum temperatures with a lesser effect on mortality from extreme-cold-temperature days. Mortality risk increases slowly and linearly for cold temperatures below the minimum mortality temperature but escalates quickly and non-linearly for excessively high temperatures (Gasparrini, 2015) (Figure 4). In certain localities, cold related deaths could decrease in climate change scenarios, but as modeled for Manhattan by Li et al. (2013), the decreased mortality during cold times of year would not compensate for the increased mortality during the warm times of year and climate change would lead to a net annual increase in mortality. A study of temperature effect on mortality in Detroit noted sharp increases in mortality and hospitalizations with extreme heat, while having more gradual increases in mortality in cold temperatures with no clear threshold (Gronlund et al. 2018). Because of the swift non-linear increase in mortality at high temperatures, it seems that an increase in high temperatures could have a large effect on heat-mortality risk, which could translate into higher health and life insurance costs. (Conroy et al. 2020)

Figure 4
CORRELATION BETWEEN TEMPERATURE AND DEATHS



Gasparrini et al. 2015

Climate change can also change the timing and frequency of extreme cold-weather events. The polar vortex (a large area of low pressure and cold air around the Earth's North Pole) remains closer to the North Pole when it is constrained by a strong polar jet stream which keeps the cold air from moving southward. A strong polar jet stream is sustained by a temperature difference between the polar region and warmer mid-latitudes. When the difference is small, the polar vortex can break off and expand as far south as Florida. The polar vortex behavior has become more extreme due to climate change since the higher latitudes warm more quickly than the mid-latitudes reducing the temperature difference between the two. When the polar vortex brings cold weather to areas unaccustomed to it, mortality can rise. The mortality from the polar vortex in 2019 was only 21 in the United States, but the 2021 polar vortex caused at least 70 deaths mainly from hypothermia in Texas.

Another effect of climate change is an increasing concentration of ground-level ozone. Warming temperatures may make some chemicals toxic at lower concentration levels. (Conroy, 2020)

Increased natural disasters increase direct mortality, while morbidity can arise from knock-on effects such as septic overflows and increased mold after floods, respiratory illnesses during/after forest fires, and lack of healthcare during and directly after disasters.

Transgenerational Effects of Environment

Genetic and epigenetic effects may also increase health care costs more than is realized. Epigenetic is defined as biochemical modifications that alter genetic expression but do not alter DNA sequence. Epigenetic effects lead to transgenerational effects. An example that has been studied the most are famine effects. Adults born to starving mothers show persistent alterations in epigenetic marks six decades after the event. Grandsons of grandfathers with low food availability actually lived longer, while grandsons of grandfathers with plenty died earlier on average (Monosson, 2015). In other examples, body mass index of young grandchildren is associated with grandfather's smoking habit and pesticide exposure can affect sperm counts into the third generation. (Monosson 2015).

EDCs also modulate epigenetic alterations changing the expression of the genome. Combined with their low-dose and nonmonotonic dose-response curves, this makes EDCs particularly dangerous and costly. Epigenetic changes involving the germline (sperm, egg) can be inherited between generations, causing diseases without a direct exposure (DiCiaula and Portincasa, 2021). Mother's exposure during pregnancy can lead to transgenerational effects with risk transmission through successive generations in the absence of direct exposure of the offspring.

Social Justice

Areas affected by pollution or other environmental degradation are, all else equal, less desirable, and thus more affordable (on the surface) places to live. The hidden costs of living in the polluted areas may in fact make them some of the most expensive places to live, but the costs are not obvious since they may not be paid monetarily, but with damaged health. For society as a whole, it would be less costly to keep areas free of pollution rather than either clean them up later and pay the increased health, loss of productivity, decrease in life enjoyment costs. Individuals, however, are likely to just move away and let "someone else" deal with the problem.

Social Justice would dictate that those in power use that power to clean up our land, water, and air so that the powerless can equally experience clean, healthy living and working areas. Since the wealthy and powerful will likely become responsible for a portion of the cost of cleanup and increased health-care expense through government subsidy, those who benefit from polluting are few while those who pay the price are many.

Conclusion

What's an actuary to do? Knowledge helps us make informed judgments when determining trend or projecting loss costs but quantifying the cost of environmental risk factors on mortality and morbidity is challenging for the experts, let alone an actuary pricing a specific product. Understanding extraneous risks, such as those described here, is clearly a step in the right direction. Addressing research gaps can be difficult, but awareness is the first step. If current measures of burden of death exclude many causes and effects due to lack of data, procuring additional data could be considered. If a specific environmental concern surrounding a specific product being priced can be identified, one could potentially find a targeted study related to that issue. Similarly, a specific geographic region may have its own data or analyses. The good news is that there are many organizations, large and small, all over the world looking at these issues and publishing studies, both broad and targeted.

An actuary should also be aware of the exposure and its effect on populations. Geography is an important consideration with environmental degradation. Some pollution is locally concentrated. For example, concentrations of benzene tend to hover near sources (oil refineries, chemical production facilities, high-traffic areas) while fine particulate matter and radiation often carry to an entire region or nation. Temporal scales of degradation differ as do the effects. For example, some air pollutants, like ground-level ozone, vary diurnally and by season which can affect how monitoring data is analyzed. Others, such as radiation affected the most susceptible cohorts (children) based on the timing of the exposure. Some pollutants build within the trophic (food) chain or within the body over time leading to latency effects on health concerns.

Actuaries should also keep in mind that in terms of exposure, workers may be more severely affected than the general public for occupational disease and exposure to temperature extremes. Workers may be required by their jobs to accept exposure and may be limited in their capacity to mitigate or avoid the associated risk. Climate change with its associated increase in catastrophic events may increase worker morbidity and mortality as workers face increasing safety hazards during rebuilding. Heat-related illnesses tend to hit workers first and hardest. Personal protective equipment may be less comfortable or even unbearable at higher temperatures (Conroy et al., 2020).

Our actions as a society are adding to human suffering and economic loss. When we degrade the environment, there are costs. Estimating them can help; eliminating them would be better.

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