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Unmasking Climate Change: How the Impacts of Global Warming Alter Disease Spread and Discovery

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Abstract

What is the relationship between global temperature increase and number of communicable disease cases, and is this relationship stronger for denser populations? Climate change and communicable diseases are two intertwined global issues. Since the start of the COVID-19 pandemic, business owners, governments, and general consumers have all realized the scale of benefits and risks of an internationally integrated global economy, and how our level of urbanization can cause rapid disease spread. This pandemic has uncovered our lack of preparation for global emergencies. Climate change not only poses a global emergency, but will also increase our world's likelihood of diseases. Rising temperatures, warmer waters, polluted air, and denser communities all put us at a greater risk for communicable disease spread. As ocean levels rise, coastal communities will be forced to densify, and simultaneously global surface temperatures will increase.

The relationships between global temperature and the number of communicable disease cases is positive. This relationship is also positive for density and number of communicable disease cases. An econometrics model with year-fixed effects and country-fixed effects are used to closely identify the causal relationship between environmental factors and diseases, while controlling for economic and health variables. Forecasting for the future, the impacts of climate change and disease spread will create instability in economic markets for both consumers and producers. Policies to mitigate both climate change and pandemics can be

economically efficient, to avoid the costly and vicious feedback loop of rising temperatures, densified populations, and disease spread.

Literature Review

Since the industrial revolution, human activities have caused global warming from the burning of fossil fuels. Generating energy, transportation, food production, overconsumption, deforestation, pollution, and habitat destruction have all enhanced the vicious feedback loop of climate change. Increased atmospheric concentrations of greenhouse gasses such as carbon dioxide, methane, and nitrous oxide have increased the greenhouse effect and caused the earth's surface temperature to rise. Additionally, our land usage has affected the reflectivity and absorption of heat onto the earth's surface from the sun's energy, leading to local warming or cooling that compounds the greenhouse effects (Environmental Protection Agency, 2022).

Our consumption and greenhouse gas usage has increased since the Industrial Revolution in the mid-1700s, the greenhouse effect has been discussed since the 1860s, and the connection between carbon dioxide increases and Earth's atmospheric warming has been known since 1938 - but we are just beginning to see the potential scale of effects of our changing climate with more data collection. The average surface temperature has risen about 2℉ (about 1℃) since the late 19th century (NASA, 2022), and the warmest years on record are within the past seven years. Some of the main concerns of climate change include **sea-level rise, ocean acidification, global temperature rise on land and in the ocean, extreme weather events, glacial retreat, and declining Arctic sea ice**. These concerns not only pose an uncomfortable future for humanity's interactions with the environment and outdoor recreation, but also can create repercussions that affect every area of life.

Pandemics are one of the numerous anticipated repercussions of climate change. In examining the main concerns of climate change, each of these effects can possibly create a greater likelihood of disease formation, spread, and therefore, pandemic occurrence. The recent COVID-19 outbreak and global pandemic has revealed the scale and vicious impacts of a feedback loop involving human activity, climate change, and pandemics. Alike other viruses, close contact between humans and animals from consumerist tactics caused the ability for virus transmission, and urbanization increased the speed and likelihood of spread. "Although the COVID-19 pandemic has been unprecedented in scale and type, such systemic, complex, compounding events are far more likely in our modern interconnected world" (Ranger, p.). COVID-19 is not alone in this evaluation, as other virus outbreaks were due to consumerism and spread through urbanization.

Consumerism is cemented within modern society's culture. Consumerism has created environmental destruction through resource extraction, mining, deforestation, habitat decimation, ocean contamination, transportation, and associated pollution. High consumption of energy, over-indulgence, and marketing strategies that tie social status and ego to material goods have altered humans and their relationship with their natural environment. An example of how consumerism has influenced this relationship is the symbol of ownership and conquering over other species, especially those endangered. This is exemplified by overfishing in the blue-fin tuna industry in Japan, trophy hunting of African Elephants, and the trafficking of endangered species into the wildlife wet markets of China (Elassar, 2019; Cruise, 2021; Vox, 2020). A fossil-fuel-dependent consumerist culture created the issue of climate change and has further exacerbated the problem with business and marketing tactics within the past century.

Fortune 500 companies have not only been reluctant to speak for environmental protection after years of development and environmental nonprofit partnerships, but the corporations have financially invested their money in the opposite direction with politics. The environmental movement is slowed by Corporate America's funding for the Republican party, which has united to oppose plans to regulate greenhouse gas emissions (Gunther, 2017). Big business is often framed in opposition to environmentalism, as environmental protections are ushered through regulation, and business prefers a lack of government intervention in order to maximize profit and sustain innovation. However, businesses have the opportunity to be part of the environmental solution with collective action, investment in future technology, and systemic changes that are better suited for a sustainable future (Lenox, 2018). This future can provide less volatile markets, sustainable resource consumption, and safer and healthier working conditions.

From a business perspective, the dangerous impacts of climate change are approaching fast, and need to be integrated into long-term strategic comprehensive business plans. The complex systems of this world and their impacts from forecasted climate change effects will be carried with a great amount of uncertainty. An increasing likelihood of pandemics is a repercussion of the lack of climate action. How bad can the effects of a pandemic be on businesses and financial institutions? "Total spending on COVID-19 response and recovery as of June 2021 totals almost $17 trillion across the 50 largest countries alone" (Ranger). Since the beginning of 2020, the United States has faced record unemployment numbers, labor shortages in what is recently being called the Great Resignation, international supply chain issues, and unprecedented inflation.

From an environmentalist and a business perspective, the reduction of pandemic occurrence and disease is optimal. As we approach the concerns of **sea-level rise, ocean acidification, global temperature rise on land and in the ocean, extreme weather events, glacial retreat, and declining Arctic sea ice**, how will these affect the likelihood of disease?

Sea levels rising

As polar ice caps and continental ice melts, our global sea level is expected to rise. This will certainly affect human populations, as around one-third of the world's population lives near coasts. Displacement of coastal populations will affect public goods, resource allocation, international ocean resource disputes, and it will "shrink local tax bases, straining municipalities' abilities to pay for public goods such as education" (Climate Central, 2019). Populations will be forced into smaller spaces, and disease is more likely to spread with increased population densities. The mobility of populations, density, level of urbanization, and the aging of populations can make communities more vulnerable to pandemics (Kaneda). As resources are shared, such as land and water, diseases can spread, and interfere with public health and human rights. From 2016 to 2021, Yemen has battled a cholera outbreak. With over one million suspected cases, the virus spread through drinking water (or consumption of contaminated food with certain bacteria), leaving the country in famine (Kirby, Vox, 2020). The loss of coastal urban regions, deforestation, and conversion of wildlands for economic development will push communities and farmers closer into the wilderness, increasing the risk of disease and food instability (Lustgarten). Increased human to animal contact and changes in farming and land practices have additional hazards.

Not only are populations denser and more vulnerable due to water levels rising, but coastal flooding can increase the risk for water-borne zoonotic diseases. As of 2003, inland floods and mudslides had not been quantitatively related to health impacts (Campbell-Lendrum, 2003). In 2011, Naicker found that flooding increases the risk of water-borne zoonotic diseases linking it to rains causing water flow to move upstream in water treatment plans (Naicker, 2011). Increased rainfall is another effect of climate change, and when compounded with eustatic sea level rise, poses a large risk for disease creation and migration of human populations.

The greatest effects of sea level rise will be felt in Asia, as it is home to the highest number of people living in the continent's low-lying coastal areas. China, Bangladesh, India, Vietnam, Indonesia and Thailand are home to the most number of people on land projected to be affected by flooding levels in 2050 (Climate Central, 2019). Tens of trillions of dollars will be the cost of flooding damages, or even trillions of dollars per year for adaptation measures, in addition to costs of supply chain disruption and limitations on ports and coastal transportations. These costs vary on climate pollution, the projected sea level rise, population growth, innovation, and migration.

Ocean acidification

Oceans have sequestered a great portion of carbon dioxide in the atmosphere. The ocean has absorbed about 525 billion tons of CO2 from the atmosphere since the industrial revolution. This warming has caused an increase in acidity of the ocean, and a drop in pH level threatens marine ecosystems (Ocean Portal Team, 2018; Naicker, 2011). Rivers and inflows of water into the ocean that carry dissolved chemicals from rocks have a stabilizing or "buffering" effect that has kept the ocean's pH stable, but the changes to ocean chemistry are occurring too fast. In the marine ecosystem, numerous species build skeletons and shells that are sensitive to acidity. Dissolved carbon dioxide in the oceans have created a surplus of hydrogen ions that have bonded with carbonate to create bicarbonate, where the carbonate cannot be extracted for the calcium carbonate shells of numerous species such as corals and oysters. The survival of these species is contingent on the chemistry of the ocean and reproduction and growth have slowed. The acidification limits coral reef habitat growth, corrodes pre-existing structures of skeletons, and causes vulnerability to erosion faster than rebuilding rates. Clams, mussels, urchins, starfish, and zooplankton will also be structurally impacted from the ocean's chemistry composition changes. Plants, algae, fish, and the greater food web of human dependency on these ecosystems will have to adjust to warmer acidic oceans.

Increased contact between animals and humans

Culture and uncertainty is ridden within the concern of increased human to animal contact. As societies urbanize, and human populations grow and become denser, addressing spillover is vital. Since an estimated ¾ of human infectious diseases are zoonotic, with over 200 currently present today, and the global emergence of diseases has increased due to human behavior (World Wildlife Fund, 2020), finding ways to reduce dangerous human-wildlife interactions is vital. There is an estimated 40,000 viruses in the bodies of mammals, a quarter of which could infect humans. But the likelihood of spillover growing, as a changing climate is forcing animal relocation (Carlson, 2019). Changing human behavior will be a difficult process because around the world, culture is ingrained into meat-based diets and industrial agriculture. The convergence of a meat-eating consumer and profit-maximizing seller without regulation has historically led to unsafe business practices. Spillover has occurred in China's wet markets since the legalization of private farming in 1978 and the use of wildlife resources after a history of fighting poverty and famines in communist China. The 1988 Wildlife Protection Law that designated wildlife as resources enforced this practice at the industrial level, and the increase in animal populations, number of species, and the lack of sanitary regulations in wet markets increased the chances of virus spread, as experienced with SARS and COVID-19. The industry has engrained these products into the culture, promoting wildlife as tonic products for citizens, meanwhile, exerting significant influence in lobbying and market power over the Chinese government, worth 148 billion yuan by 2018 (Vox, 2020). The market-selling and buying of agriculture is only one piece of the puzzle, encompassed by the global issues of land conversion for intensified agriculture, habitat fragmentation, deforestation, and illegally traded wildlife (World Wildlife Fund, 2020; Mills, 2010). Policy, culture, and human behavior of human-animal interactions will all need to be monitored in a world with an increased likelihood of pandemics.

Will species loss affect the likelihood of virus transmission? According to the dilution effect, yes. As deforestation and climate impacts increase biodiversity loss, the transmission of zoonotic diseases is claimed to be more likely. The “dilution effect” claims that in regions of high biodiversity, more species sustain vectors, and the disease is diluted, and with fewer species, the burden of disease is higher (Naicker, 2011). Highly specific pathogens will disappear with their hosts, but the extinctions are more likely to occur in selective dietary specialist habitats, while generalist species may thrive in the absence of competition from specialists (Mills, 2010). Additionally, lowland tropical areas are particularly susceptible to high extinction rates because of restricted geographical range and limited dispersal capabilities (Mills, 2010). Human to animal contact will become increasingly risky as species biodiversity decreases, as zoonotic diseases will no longer be diluted.

Warming temperatures

Tropical region expansion

Rising average global surface and ocean temperatures pose numerous risks for humans and pandemics because disease ranges are shifting. The recent average global temperature increases are primarily due to greater emissions of greenhouse gasses. By the end of the century, the Intergovernmental Panel on Climate Change predicts a mean temperature rise of 1.8℃ to 4℃ (Naicker, 2011). As the ranges of mosquitoes, ticks, and sandflies shift with temperature changes, a greater risk for West Nile Virus, Zika, dengue, chikungunya, and malaria are present (Mills, 2010, Welch, Goodell). Lyme disease from ticks formerly was only a summer concern, or not even present in certain regions until recently (McDermott, 2022). This disease was once largely limited to the south, but hosts today are as far north as Sweden (Welch). It is estimated that in 2080, 60% of the world will be at risk as Zeka will be expanding its latitudinal range (Goodell). As the tropical ranges shift, their disease vectors will advance to latitudes they were previously unhabitable in, affecting the accessibility for human migration, travel, health care, and sanitation standards.

The range shifts of temperatures impact the migration of animals and the number of “first encounters” between species. Mammal migrations across latitudinal gradients have few first encounters because the migrations are typically of entire biome assemblages. The Amazon basin, African basin, Botswana, and parts of the Indian subcontinent have low first encounters because of the homogenous climate that may warm too much for species to retreat to high-elevation refuges. In 2021, Carlson found that the “re-organization of mammal assemblages” is projected to have a total of 316,426 (+/- 1,719) first encounters and would lead to a minimum of 15,000 cross-species transmission events of at least one novel virus between a pair of host species. Most sharing would occur in “high-elevation, species-rich ecosystems in Africa and Asia” (Carlson, 2021, p. 5). These locations are concerning considering the expected increases in temperature and population density. The “combined effects of temperature and humidity affect the behavior, survival, and reproduction of many vector species...these examples indicate that host responses to climate change are multifactorial and their quantitative prediction must consider multiple variables simultaneously, including temperature, precipitation, altitude, and location” (Mills, 2010). As climate change arises with its own challenges, its impacts on population models and virus transmission also adopts complexity, uncertainty, and mutli-variablility.

Bacteria growth in warmer waters

Warmer temperatures in our oceans pose a risk of increased bacteria growth and illness from human recreation and consumption of marine wildlife. Cholera and non-cholera Vibrio sicknesses have been increasing around the globe, with the constant variable of rising temperatures. In 2014, less than 200 miles from the Arctic circle in the Baltic Sea, citizens from Finland and Sweden had rashes, sores, and skin lesions from a vibrio-related illness during a heatwave, breaking a record for the sixth time in 20 years (Welch). Vibrio infections are becoming widely studied in Europe as case numbers expand, as the genus *Vibrio* and the human pathogen *V. cholerae* have increased in prevalence in the coastal North Sea in the last 44 years. Meanwhile, the surface sea temperature in coastal European seas have increased 4-7 times faster than global oceans within the past few decades (Le Roux, 2015). This concern will expand beyond Europe as the world’s oceans warm to new temperatures.

Increased rainfall

Increased rainfall can provide more habitable conditions for disease carrying vectors. North American deer mice populations increased from 1995 to 2000 in Colorado from increased rainfall during warm periods, but these populations fell after rainfall during cold periods (Mills, 2010). Malaria was linked to an increase in precipitation and higher temperatures in Kenya, whereas reduced rainfall in Niger and Senegal lead to decreases in Malaria (Mills, 2010). Rift Valley Fever outbreaks increased during periods of heavy rainfall, as mosquitos are floodwater breeders, with eggs deposited during heavy rains that remain viable during drought. The increase in vegetation density aided the protection of these vectors. East Africa is expected to have heavy rainfalls and therefore more Rift Valley Fever outbreaks (Naicker, 2011). A study conducted to see increases of hospitalization of diarrhoeal diseases from rainfall and humidity changes found no association in Lima, Peru, but a 3% incidence increase in Fiji (Campbell-

Lendrum, 2003). Rainfall effects on disease pose a high uncertainty, and are forecasted to affect food trade and socioeconomic conditions.

Melting Permafrost and Ice

Melting due to global temperature rise will release methane and carbon dioxide into the atmosphere and decrease the albedo effect, furthering climate change’s vicious feedback loop. Melting of permafrost ice will cause the release of ancient dormant viruses into the atmosphere, causing future large-scale disease outbreaks. The diseases from permafrost, frozen soil, have already infected our society. In 2014, an ancient virus Pithovirus sibericum was resurrected in Siberia permafrost after 30,000 years. In August 2016, 20 people in Russia were hospitalized and a 12-year old died from being infected by a deadly anthrax bacteria that had been trapped in permamfrost for 75 years, from the carcass of a reindeer killed by the bacteria (Zurich, 2020). Arctic sea ice melting will also affect novel viral transmission between pinnipeds and sea otters (Carlson, 2021). Phocine distemper virus (PDV) has caused extensive mortality in sea otters, and exposure to the virus is expected to increase with Arctic Ocean sea ice reductions (VanWormer). The melting of permafrost and Arctic ice carries strong uncertainties of pathogens released into our atmosphere and risks of human exposure.

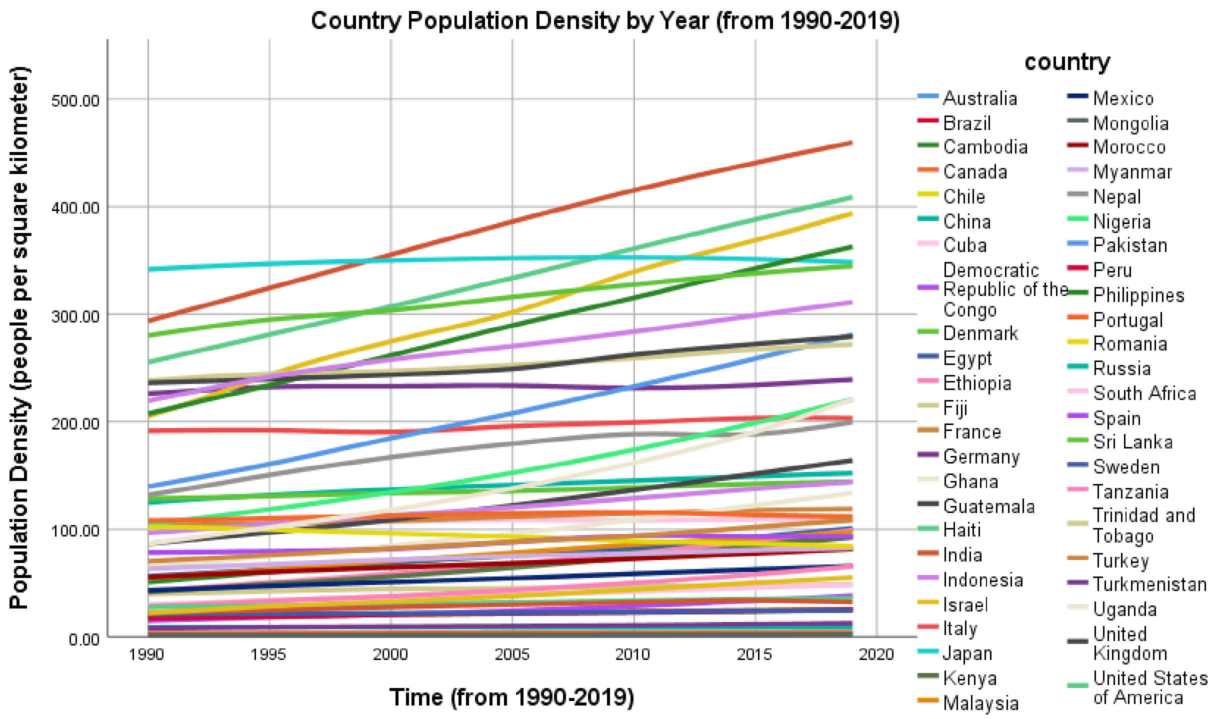
The Human Response

Immune Systems

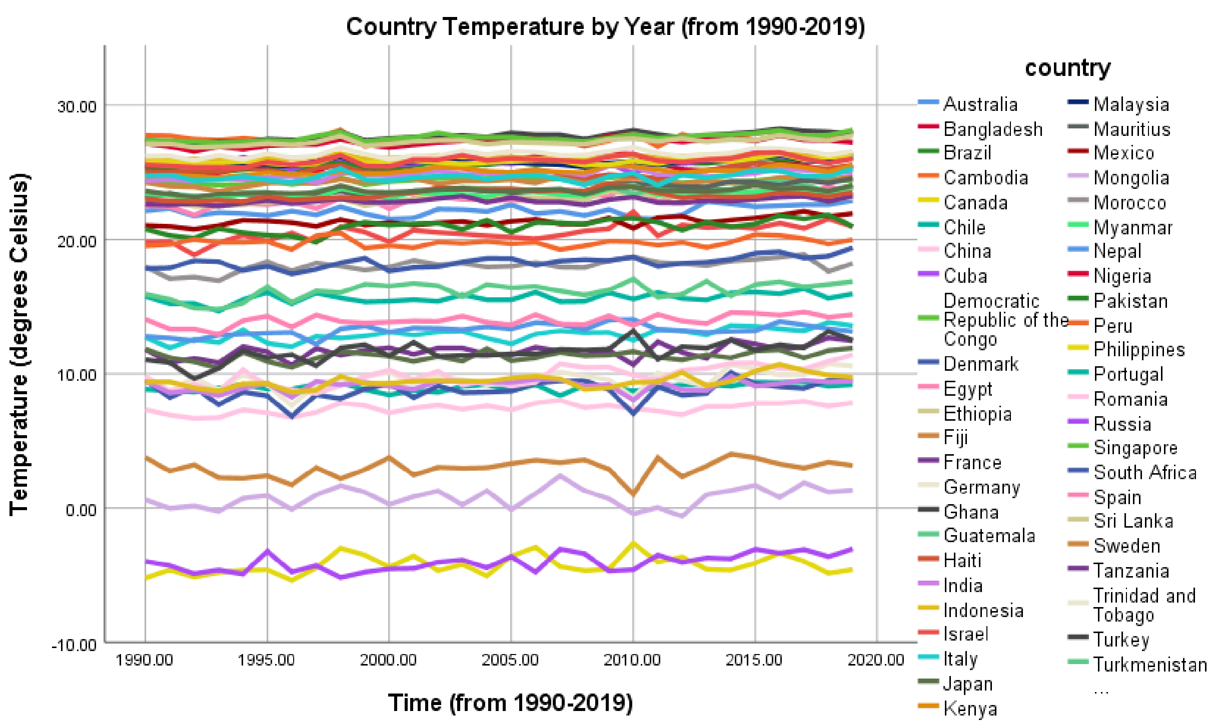
All climate change factors are deeply integrated in affecting the human-immune system and policy health response to viruses. With increased temperatures, changes in rainfall, and humidity, the human immune system response will be compromised, in collaboration with environmental and resource dangers. This can include a lack of nutritious foods due to changes in weather and unsafe or inhabitable conditions. Population demographics are a concern of risk of infection, as older populations are at greater risk for contracting viruses, and we have experienced declines in fertility rates and increases in the share of older populations (Kaneda). Increasing fertility rates is not a solution to this conundrum, as population density is a threat to virus spread and animal to human spillover. As human and animal contact increases, there is a “critical need for health monitoring and identification of new, potentially zoonotic pathogens in wildlife populations” for forecasting and measuring emerging infectious diseases (Jones). Wildlife population changes and their migration patterns will affect our climate change and virus responses. Declining biodiversity will decrease our ability to contain viruses once they have started. Humans have relied on nature, as natural medicines are deep in the supply chain of pharmaceutical products (Zurich, 2020). The threats to human medical responses, the threats to the human immune system and its supports from our level of urbanization, and the environmental changes that put humans at greater risk of contracting disease all are of concern within climate change impacts.

Cases

Population density historical data and future data projections for all of the countries were retrieved from Our World in Data source which uses the World Bank and the UN World Population Prospects. The graph below shows 50 of the 53 countries' changes in population. Bangladesh, Mauritius, and Singapore are excluded for outlier and graph visualization purposes, but have each experienced density increases. The only countries that experienced decreases in population density from 1990-2019 were Romania and Russia.



In examining individual countries, the average mean surface temperature has slightly increased. Temperature data was gathered from the World Bank's Climate Change Knowledge Portal (CCKP)



The dependent variable of disease death counts was gathered from the Institute for Health Metrics and Evaluation based at the University of Washington using their Global Burden of Disease dataset. Data on 18 different was collected including viruses, parasites, and bacteria. All diseases here are contagious, only two of them (campylobacter and non-typhoidal salmonella) have a low chance of spreading from person to person. The bacterial disease data used include Haemophilus influenzae type B, pneumococcus, clostridium difficile, aeromonas, campylobacter, enterotoxigenic E. coli, cholera, enteropathogenic E. coli, shigella, non typhoidal salmonella, and meningococcal meningitis. The diseases from parasite infection include cryptosporidium and entamoeba, and the virus data used include respiratory syncytial virus, influenza, adenovirus, norovirus, and rotavirus. Bacteria and viruses do not need a host and can be transmissible through objects or surfaces, whereas parasites need a living host to survive. Bacteria and parasites can be killed with antibiotics, but not viruses. Zoonotic diseases can be caused by viruses, bacteria, parasites, and fungi (Nationwide Children's Hospital, 2021). The diseases resulting from the viruses, bacteria, and parasites can be found in water, soil, the surfaces of foods and objects, and feces, and can be transmitted in a variety of ways.

Bacterias

All of the bacterial diseases can be contagious from one person to another, besides the foodborne illnesses of campylobacter and non-typhoidal salmonella. They each pose their own risks for increased frequency and spread with the discussed effects of climate change. Haemophilus influenzae type B (or Hib) is a bacterial virus in the nose and throat that can be invasive to other parts of the body. The invasive diseases caused by this bacteria include pneumonia, bloodstream infection, meningitis, epiglottitis, cellulitis, and infectious arthritis. It spreads through respiratory droplets and is a disease of concern for populations increasing in density. It occurs mostly in young children, the elderly, and people with certain medical conditions. There is a possibility of re-infection after getting it, and there are preventative antibiotics and vaccines for the bacteria (Centers for Disease Control and Prevention, 2022). Pneumococcal bacteria can cause lung, blood, sinus, and ear infections as well as meningitis which is an infection of the brain lining and spinal cord. This bacteria spreads through direct contact with respiratory secretions, it can affect all ages of a population, and there are vaccines available (Centers for Disease Control and Prevention, 2020). Meningococcal meningitis is spread person-to-person through respiratory and throat secretions. There are vaccines and antibiotics available, but even with antibiotic treatment, the bacterial disease occurs 10-15% occurrence of death, and one-fifth of survivors have long-term disabilities (Centers for Disease Control and Prevention, 2022). This disease is a concern to a changing climate in terms of denser populations and threats to our healthcare system responses. Clostridioides difficile (C. diff) is a bacterium that infects the large intestine (colon), and causes severe diarrhea. It can affect anyone but most severely affects older populations, and to prevent its spread to others it is recommended to wash and shower frequently with soap and use a separate bathroom (Centers for Disease Control and Prevention, 2021). This bacteria is certainly of concern for denser populations.

Threats to our nutrition, agriculture, water and sanitation systems put us at risk for numerous diseases. Aeromonas is a bacteria that is distributed in groundwater, freshwater, and marine environments and includes a wide spectrum of diseases including diarrheal diseases. It is in animals such as fish, reptiles, amphibians, mammals and humans. This bacteria grows at a range of temperatures but they increase in frequency during warmer months with warmer waters and soil (Morris, 2021). An increase in global and sea temperatures causes concern about the spread of this bacteria. Aeromonas infections can occur from drinking or handling contaminated water, and can also be found in fresh produce, meat, and dairy products (Public Health Agency of Canada, 2012). Campylobacter is a bacterial infectious disease that can be caused by contamination in eating undercooked or raw meat, drinking raw milk, eating contaminated produce, drinking contaminated water, or having human contact with animals and their environments. Campylobacter infections do not need antibiotics, and some bacteria are resistant to antibiotics (Centers for Disease Control and Prevention, 2019). This disease is a concern in regards to denser populations, threats to our healthcare and nutrition/agriculture systems, and future clean water access. Enterotoxigenic Escherichia coli (E. coli, or ETEC) and Enteropathogenic E. coli (EPEC) are bacteria and the leading cause of travelers' diarrhea and diarrheal disease in lower-income countries, especially for children. It is transmitted through human or animal fecal contamination of food or water (Centers for Disease Control and Prevention, 2014; Ochoa, 2012). This bacteria is a concern for denser populations, increased animal-to-human contact, and climate change-induced threats to our nutrition and sanitary systems. Shigella bacteria is an infection common among young children and travelers and can occur from contact with stool or contaminated foods and water. It can also be contracted from anal sex due to stool contact (Centers for Disease Control and Prevention, 2021). Salmonella is 1 of 4 global causes of diarrhoeal diseases and can pass through an entire food chain. Person-to-person transmission is uncommon but can occur through fecal-oral contact, but humans coming into contact with infected animals and pets can also cause the disease (WHO). This poses risks for a future of increased human to animal contact.

Cholera is a diarrhoeal disease that can cause symptoms between 12 hours and 5 days after ingesting food or water that is contaminated, and the disease can kill within hours if untreated. There have been numerous worldwide outbreaks, and the disease is now endemic in many countries. Safe water and sanitation are important for the prevention and control of waterborne diseases such as cholera. There are oral vaccines available for cholera, and if infected there is an oral rehydration solution. The vibrio cholerae strains O1 and O139 cause outbreaks (WHO). "The consequences of a humanitarian crisis – such as disruption of water and sanitation systems, or the displacement of populations to inadequate and overcrowded camps – can increase the risk of cholera transmission, should the bacteria be present or introduced" (WHO). The World Health Organization in collaboration with the Global Task Force on Cholera Control has a goal set to end Cholera by 2030, which involves sustainable development goals to ensure good hygiene practices, universal access to safe water, and adequate sanitation as a vital part of economic development (WHO).

Parasites

Cryptosporidium or "crypto" is a microscopic parasite that causes diarrheal disease. The parasite has crypto has zoonotic species and genotypes, as well as non-zoonotic and genotype species that are host-adapted. Crypto therefore can infect animals and humans, and it is most often contracted by swallowing or drinking contaminated water (Centers for Disease Control and Prevention, 2019). The parasite is a leading cause of waterborne disease in the United States. Cattle, birds, and reptiles are major hosts of the parasite (Centers for Disease Control and Prevention, 2019). The parasite crypto may increase in frequency with the impact of increased animal-to-human contact.

The entamoeba histolytica parasite causes the disease amebiasis. Anyone can contract the disease but it is most common in tropical areas or developing countries (Centers for Disease Control and Prevention, 2021). The entamoeba species is frequently recovered from freshwater contaminated with human feces (Centers for Disease Control and Prevention, 2019). This disease is a risk with the consequences of climate change including flooding and threats to sanitary systems.

Viruses

Respiratory Syncytial Virus Infection (RSV) is a respiratory virus that easily spreads through the air. This virus is of high concern in denser populations because of its ease of spread (Centers for Disease Control and Prevention, 2021). Influenza, or the flu, has had a long history, but the virus has the potential for causing pandemics and rapid outbreaks. In 1918 a global influenza pandemic began from the H1N1 flu strain, of which the genes originated in a bird. It is estimated this outbreak infected 500 million people, and killed approximately 50 million. Influenza is a concern regarding future outbreaks, increases in density, human-to-animal contact, and weakening of pharmaceuticals (Centers for Disease Control and Prevention, 2018). Adenoviruses are typically spread through close contact with an infected person, the spread of their air droplets, or from touching contaminated objects. These viruses are common in children, and certain types of the virus can cause outbreaks. This virus among the other diseases exemplifies uncertainty within epidemiology, as it is currently being tested for causing hepatitis. This virus is a risk for denser populations, and uncertainty within the disease knowledge (Centers for Disease Control and Prevention, 2022).

Norovirus is very contagious, causes vomiting and diarrhea, and can be transferred from an infected person, contaminated surfaces, or the consumption of contaminated food or water. The immunity length and effectiveness of other strains is unknown. The virus is usually brief in healthy people (Centers for Disease Control and Prevention, 2021). In April of 2022, an outbreak of norovirus occurred from contaminated raw oysters from British Columbia (Centers for Disease Control and Prevention, 2022). This virus has the potential to cause outbreaks with its high level of contagion, especially in denser populations dependent on animals for consumption. Rotavirus spreads easiest among young children and is contracted through stool contamination on objects or surfaces, as well as contaminated food. A vaccine for rotavirus is available and can strongly prevent infant deaths (Centers for Disease Control and Prevention, 2021).

Hypothesis

Based on my literature review, my hypothesis is that as temperatures and population densities increase, there is an increase in virus cases. My null hypothesis is that *as temperatures and population densities increase, there is no effect on the number of virus cases*. My alternate hypotheses are in regards to if only one of the two variables examined are significant with a positive relationship. This includes the alternatives of as temperatures increase, there is an *increase in the number of virus cases holding population density constant*. The second alternate hypothesis is that as population densities increase, there is an *increase in the number of virus cases holding temperature constant*.

Within climate change literature, the concern is that the hazards and negative impacts of climate change will affect vulnerable regions of lower economic development the most (Phillips). From this perspective, an additional alternate hypothesis is that each of the claims stated above will have stronger coefficient values for the density and temperature variables for “poorer” countries rather than “richer” countries, indicating a larger impact on disease deaths from density and temperature increases.

Methodology

An econometrics model was used to determine the relationship between temperature and density changes in disease deaths for 53 countries over 30 years, from 1990-2019. To avoid omitted variable bias, the variables controlled for include infant mortality numbers per 1000 births and GDP per capita. These are to capture economic and health system indicators that would influence disease death counts and could possibly be correlated with temperature or population density. Infant mortality proxies for a country’s health system, and therefore within the regression, a positive relationship is expected between infant mortality and disease. A country with high infant mortality signals a poorer healthcare system that is less prepared to mitigate disease deaths and therefore is expected to have a positive increase in disease deaths. If a country has a higher infant mortality rate, then disease deaths may be due to a poor healthcare system rather than increases in temperature or density. GDP per capita was used to represent economic-well being of a country, and this variable should have a negative relationship with disease death counts. As a country's GDP per capita increases, disease deaths should decrease because an individual can purchase better health care. This variable of GDP per capita is less direct (or certainty in being a negative relationship) than the direct relationship with infant mortality, because a greater GDP per capita may represent wealth and travel frequency, and the mobility of citizens could have a positive relationship with disease deaths. Both year and country variables had fixed effects. Country fixed effects compare a country to itself over time, controlling for unseen variables that are unique to a country that may affect disease deaths. An example of this would be low amount of government services, as this doesn't change much within a country over time. Year fixed effects compare countries relative to each other within the same year, controlling for common shocks to all countries' disease deaths in a year. The epsilon (ε) within both regressions represents the error term of the linear regression model.

Data was gathered from 53 different countries, spanning different geographic regions, and finding variance in the dependent variables investigated. These countries included Australia, Bangladesh, Brazil, Canada, Cambodia, Chile, China, Cuba, Denmark, Democratic Republic of the Congo, Egypt, Ethiopia, Fiji, France, Germany, Ghana, Guatemala, Haiti, India, Indonesia, Israel, Italy, Japan, Kenya, Malaysia, Mauritius, Mexico, Mongolia, Morocco, Myanmar, Nepal, Nigeria, Pakistan, Peru, Philippines, Portugal, Romania, Russia, Singapore, South Africa, Spain, Sri Lanka, Sweden, Tanzania, Trinidad and Tobago, Turkey, Turkmenistan, Uganda, United States, United Kingdom, Venezuela, Vietnam, and Yemen.

$$All\ Countries:$$

$$Disease\ Deaths = \beta 1 temperature + \beta 2 density + \beta 3 GDP\ per\ capita + \beta 4\ infant\ mortality + \varepsilon$$

The outputs of “disease deaths” are disease deaths per 100,000 people, resulting from the 18 disease based on the model of all 53 countries. In the main model, there was a significant relationship found for the variables density, temperature, and infant mortality, but not for GDP per capita. Density has a significant relationship at the 10% level, and claimed in increase in 100 people per kilometer squared lead to an increase in disease deaths by less than 1, at 0.19 more deaths per 100,000 people. An increase in 1 degree celsius lead to an increase in disease deaths by 2.24 of 100,000 people, this relationship significant at the 10% level. GDP per capita had no significant relationship. Infant mortality had the expected positive relationship, of an increase in infant mortality by 1 death per 1,000 births lead to an increase in disease deaths by 3.14 of 100,000 people, significant at the 10% level.

To examine the impact of density and temperature changes on countries from an equity analysis perspective, two different regressions were run for “rich” and “poor” countries using a dummy variable. This is a concern within climate change impacts, the impact on vulnerable and poorer countries is anticipated to be worse than rich countries (Phillips).

$$High\ vs\ Low\ GDP\ Countries:$$

$$Disease\ Deaths = \beta 1 temperature + \beta 2 density + \beta 3 GDP\ per\ capita + \beta 4\ infant\ mortality + \beta 5 rich + \varepsilon$$

In this model, “rich” is a dummy variable for an average GDP per capita above or below $15,000. This number was chosen because it captured the upper quartile of the 53 countries examined. The countries included within “High GDP” were Australia, Canada, Denmark, France, Germany, Israel, Italy, Japan, Portugal, Singapore, Spain, Sweden, United Kingdom and the United States.

When examining the split between the “rich” and “poor” countries, all three variables of density, GDP per capita, and infant mortality of both groups were significant at the 1% level. The results for these countries showed an increase in density by 100 people per kilometer squared led to a prediction of an increase in the 18 diseases by less than 1, at 0.43769 disease deaths per 100,000 people. There was no significant relationship for temperature. GDP per capita had a negative relationship of a $100 increase in GDP per capita led to a small decrease in disease counts, by about 0.03 per 100,000 people. Infant mortality had an unexpectedly negative relationship, as an increase of infant mortality rate of 1 death per 1,000 births lead to an decrease in disease cases by 3.12 per 100,000 people. This relationship was most surprising, and omitted variable bias may be underlying in this relationship, as more variables on health and economic factors may clarify this relationship.

For the economically “poor” countries of the lower 75%, there was a much greater coefficient for density effects on disease deaths. An increase in density by 100 people per kilometer squared led to a prediction of an increase in 12.58 disease deaths per 100,000 people. This number is nearly 30 times larger than the rate for disease deaths in the richer countries, and justifies the concerns within an equity analysis of how countries with higher or lower GDP values and economic systems are able to mitigate disease deaths in dense populations. The temperature variable had no significant relationship. An increase in $100 GDP per capita led to an increase in disease deaths by 0.35 per 100,000 people. This relationship is small, but was expected to be negative. This relationship may be due to some omitted variable bias, as GDP per capita may be adopting high levels of economic activity as high levels of citizen’s mobility and desire to travel, which would lead to an increase in disease spread from more mobility and groups of people to come into contact with. Regardless, this significant positive relationship gives concern to the countries currently in development and mitigating disease. Infant mortality was positive as expected, as an increase in 1 death per 1,000 births lead to an increase in disease deaths by 2.94 per 100,000 people.

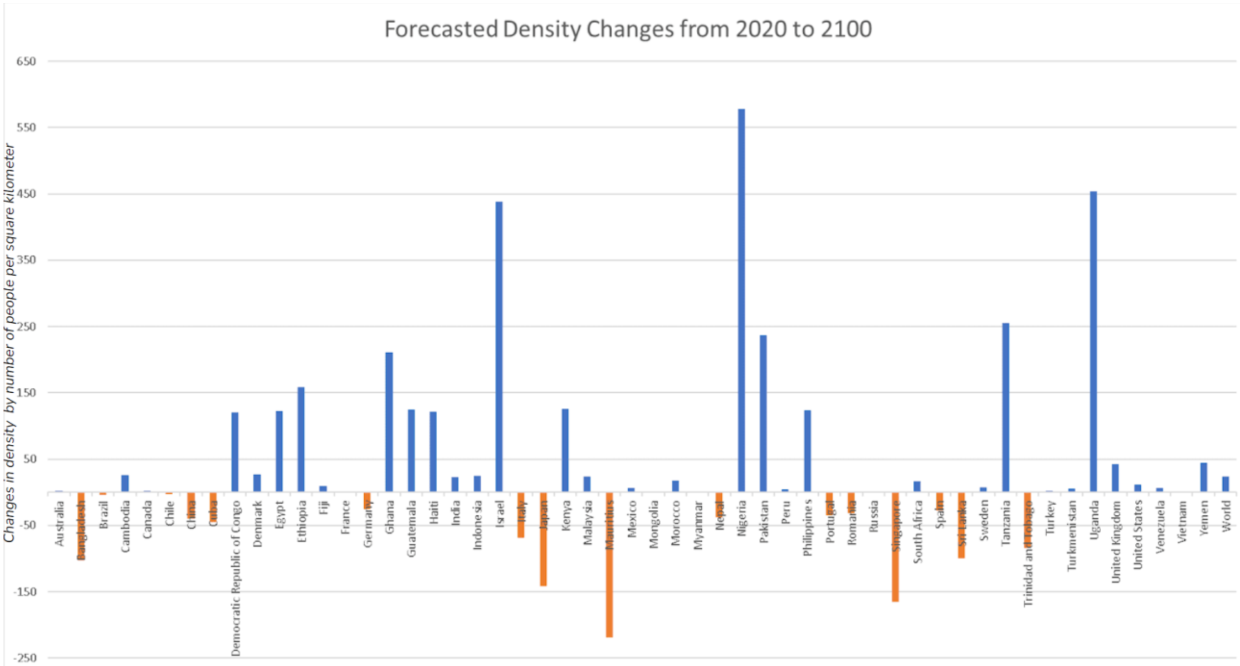
	All Countries	Upper 25% average GDP	Lower 75% average GDP
Density *(Increase in 100 people per km^2)*	**0.19338*** 0.10302	**0.43769***** .0654	**12.57499***** 2.55514
Temperature *(Increase of 1 degree Celsius)*	**2.244477*** 1.230364	0.5327533 0.5958491	2.140637 1.935245
GDP per capita *(Increase in GDP by $100 per capita)*	.00269 .01175	-0.02977*** .00586	0.35029*** 0.04237
Infant mortality *(Increase in 1 per 1,000 births)*	3.139318*** 0.1233619	-3.117866*** 0.6715313	2.940413*** 0.1451139

*P < 0.10; **P < 0.05; ***P < 0.01

The "All Countries" model is more robust for density and temperature forecasts, as both coefficients were significant. Additionally, the negative relationship with infant mortality in the "rich" countries shows concern as this relationship was expected to be positive. GDP per capita was not significant in the "All Countries" model, due to omitted variable bias of mobility within a country. As wealth of individuals increases, their mobility or desire to travel could create an increase in disease spread, therefore hiding a positive relationship, when GDP per capita was expected to have a negative relationship with disease deaths.

Forecasting

Future values of temperature and density are debated, but using the Our World in Data and World Bank Group dataset as a source for density increases by 2100, the countries that are expecting the greatest increases in density are Israel, Nigeria, and Uganda of the 53 countries explored within this dataset. The marginal effects of a density increase of 0.19338 per increase in population of 100 people per square kilometer will lead to a 0.85 increase in disease deaths per 100,000 population in Israel, a 1.12 increase in disease deaths per 100,000 population in Nigeria, and a 0.89 increase in disease deaths per 100,000 population in Uganda. Population densities can be influenced from societal changes, but these forecasts offer insight on the risks and marginal effects of density on disease deaths from the model.



Countries within the northern regions have experienced high temperature increases and are forecasted to experience additional temperature increases. With low emission (RCP 2.6), medium emission (RCP 6.0), and high emission (RCP 8.5) projection scenarios from the Climate Change Knowledge Portal, the marginal effects on disease deaths with a temperature coefficient of 2.244477 can be found. (RCP is the Representative Concentration Pathways of different emission scenarios and concentrations of greenhouse gasses, and land use and land cover (Climate Change Knowledge Portal, 2021). Holding other variables constant to see the marginal effects of temperature changes shows that in Canada, the low, medium, and high emission scenarios are projected to lead to 1.68, 8.39, and 14.27 disease deaths per 100,000 population of the 18 diseases investigated. In Russia, the low, medium, and high emission scenarios are projected to lead to 1.48, 7.79, and 15.64 disease deaths per 100,000 population of the 18 diseases investigated. In Sweden, the low, medium, and high emission scenarios are projected to lead to 1.05, 5.18, and 10.15 disease deaths per 100,000 population of the 18 diseases investigated. In the United States, the low, medium, and high emission scenarios are projected to lead to 1.23, 4.42, and 11.11 disease deaths per 100,000 population of the 18 diseases investigated.

	Low Emission	Medium Emission	High Emission
Canada	1.683358	8.394344	14.27487
Russia	1.481355	7.788335	15.644
Sweden	1.054904	5.184742	10.14504
United States	1.234462	4.42162	11.11016

Conclusion

The issue of climate change within policy should be as urgent as the policies of disease mitigation. Within the environmental studies discipline, there is a belief that science can solve all of our issues. However, this implementation of science does not come with full-proof solutions, examples include the anti-mask, anti-vaccine and the general anti-science movements. As explored in the literature, exemplified in pharmaceuticals and infrastructure crowding, abilities in science will be limited by climate change-induced resource destruction. The argument that science will solve all of our issues neglects the possible societal changes of human rights restrictions. It also lacks equity considerations, as climate change is forecasted to impact underdeveloped countries before the developed countries, who unfairly carry much of the environmental destruction and pollution budget. In terms of environmental justice and assisting developing countries, “wealthy countries must provide budget support both to maintain these basic services in the near term and to invest in climate-resilient infrastructure to manage long-term risk…Beyond universal health coverage and proactive climate resilience measures, both climate change adaptation and pandemic preparedness can be framed as part of countries’ legal obligation to realize the right to health through their laws, policies and budgets" (Phillips). Climate change is a global issue and countries must work in collaboration to mitigate its effects.

Reducing uncertainty within economics and policy requires bridging the gap between epidemiologists or ecologists, and those who make policy decisions for business. Effective communication strategies and employing professionals to translate the hard science into policy implementation can help avoid targeted political goals. The value of this econometrics model is important as it can be applied to disease deaths, and directly relate to financial losses within economic models. Refining this model and using the outputs of potential disease deaths or cases can be put into dollar terms to evaluate the severity from an economic perspective. Data analysis of disease rate from environmental changes can directly relate to output, profits, or production value lost from an employer's perspective, if workers are missing time from being sick or do not recover to full levels of productivity. Using this interdisciplinary approach can help foster a conversation for someone who values economic variables but does not value environmental activism for climate change mitigation or true sustainability.

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