A Bat Sneezed and The Economy Collapsed

Launching the Fourth Industrial Revolution in a Pandemic Age

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Idea in Brief

- Mass Production, Lean Production, and bottom-line financial metrics created unprecedented value to society in the early 20th century but have now reached their limits and create a global systemic risk. The aerospace industry has been particularly hard-hit.
- The human population footprint has expanded into the former wilderness where viruses thrive in rodents, birds, pigs, and bats. COVID-19 is the sixth pandemic of the 21st century, and we can expect more to follow.
- Societal growth requires new technologies and new management theory, as envisioned in the Fourth Industrial Revolution. Products will become connected and autonomous, and economics will measure impacts on People and the Planet, as well as Prosperity. This is known as the Triple Bottom Line.

Introduction

An aerospace conference kicked off on January 6, 2020 with a variety of face-to-face networking sessions… and by March of that year this seemed unimaginable as the world suffered the effects of the COVID-19 pandemic. In early January, the only known cases were in Wuhan China, but later research found that unrecognized cases existed in the US, France, and Italy as early as December 2019.

This is all by way of saying that two days after speaking at the conference I developed 15 days of COVID-like symptoms. I recovered completely, but as a rhetorical device let's assume that the Coronavirus was present at the conference and became a 'spreader event' affecting members of the aerospace community. Imagine further that the event's attendees returned to their offices and spread the virus, infecting the entire profession, and that every engineer, every designer, every maintenance technician, every employee at every aerospace manufacturer or supplier world-wide were simultaneously laid-up with COVID-19, in turn shutting down the world's ability to produce aircraft.

This hypothetical is better than the actual situation faced by the commercial aerospace industry today.

Traveler throughput collapsed in April, and by late September was still 70% below 2019 levels (Figure 1), as travelers are uninterested in air travel. The airlines have lost tens of billions of dollars, expect a return to pre-COVID levels is years away, and will require the widespread use of a vaccine. Boeing, Airbus, and their suppliers have cut tens of thousands of jobs (Conger and Griffith 2020). Dramatic shifts are taking place in the economics of airline profitability and the manufacturers which serve them.

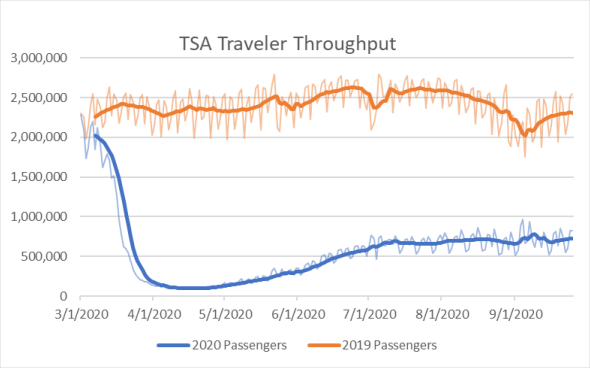

Figure 1: Number of Air Travelers
https://www.tsa.gov/coronavirus/passenger-throughput

The industry relies on world-wide public health as travelers consider their entire infection risk, from the time they leave home until they return. It is not enough for aircraft, airlines, and airports to protect passengers: what about the taxis, the hotels, the offices, the restaurants, and the theme parks?

Destination locations face risks as well. Respiratory viruses may spread long before they are recognized. The SARS-CoV-2 virus originated in bats, jumped to humans in China, then Europe, New York, throughout the U.S. the world, and even animals in the Bronx Zoo (McAloose 2020). Since the outbreak, nations and states have closed their borders and are enforcing quarantines upon arrival; business trips which formerly took a week now require a month, if the traveler is allowed to enter at all.

Is This the Economy That We Want?

From the New York Times on 15-July (Tankersley and Casselman 2020):

> "WASHINGTON — The United States economy is headed for a tumultuous autumn, with the threat of closed schools, renewed government lockdowns, empty stadiums and an uncertain amount of federal support for businesses and unemployed workers all clouding hopes for a rapid rebound from recession.
>
> "… failure to suppress a resurgence of confirmed infections is threatening to choke the recovery and push the country back into a recessionary spiral — one that could inflict long-term damage on workers and businesses large and small…
>
> "Most economists abandoned hope for a "V-shaped" recovery long ago. Now they are warning of an outright reversal, with mounting job losses and business failures. And this time, much of the damage is likely to be permanent."

The Economist, on 1-August ("Air travel's sudden collapse will reshape a trillion-dollar industry." 2020):

> "Around 35% of the global fleet of around 25,000 aircraft is still parked—less than the 70% at the height of the crisis in April but still terrible. Even if traffic recovers to 80% of last year's levels in 2021, as some optimists expect, plenty of aeroplanes will remain on the ground. Citigroup, a bank, forecasts excess capacity of 4,000 aircraft in 18 months' time."

And the Wall Street Journal on 2-September (Cameron 2020):

> "The pandemic is set to have an even deeper and longer-lasting impact on airlines' finances than 9/11, several industry executives have said. Carriers have spent months trying to get passengers back onto planes after the pandemic nearly halted travel in the spring, including by developing more-thorough cleaning procedures and toughening rules requiring passengers to wear masks. Nevertheless, travel demand has stalled at around 30% of last year's levels. Executives believe it will take years—and likely a vaccine—for it to fully rebound."

Similar issues exist in the commercial real estate market. The Time-Life Building in Manhattan houses 8,000 workers at its peak, but the daily average in July was about 500. Street level retail establishments closed, hot dog sales dropped from 400 per day to 10, and investment banks with tens of thousands of workers in the New York City area found that they do not need to operate in the City. If workers no longer commute to their local office, why would they take a business trip to an office in another city? The business market for air travel generates two-thirds of airline earnings ("How Much of Airlines Revenue Comes from Business Travelers?" 2019), and as it collapsed in April, the Zoom online meeting platform grew from 10 million to 300 million daily participants, echoed by growth at Microsoft, Google, and Cisco (Tara 2020). The internet is replacing business travel.

Systemic Risk Impacts Commercial Aerospace

The thesis of this chapter is that the World is a global system, and each industry affects the others. Regions in southern China grew to meet the needs of the global automotive industry, which in turn led to a human-viral spillover, and infected airline passengers spread the virus throughout the world. Travel and entertainment industries collapsed as we all await improvements in public health.

A century ago, as Henry Ford, William Boeing, and others created prosperity through high-volume mass production they did do so with little concern for the affects one industry had on another, or how they affect the planet as a whole. Since then the human population quadrupled, and only one-quarter of the planet's surface remains wild. Prosperity and population grew until by the planet; the challenges that humanity (including the aerospace industry) faces are of our own making.

This chapter follows three main themes:

- A short history of the Industrial Age divided into four 'Revolutions'.
- A description of 'Systems Thinking', using events of the COVID-19 pandemic as examples.
- Predictions for future decades, as technology and economic goals address the necessary 'triple-bottom-line' of Planet and People, and Prosperity.

Industry 2.0: Mass-producing an Efficient Pandemic

Klaus Schwab, head of the World Economic Forum posits that there have been four revolutions in the Industrial Age (Schwab 2015):

- "The First Revolution used water and steam power to mechanize production,
- The Second used electrical systems to enable mass production,
- The Third saw the introduction of electronics and information technology to automate production,
- The Fourth is blurring the lines between the physical, digital, and biological spheres."

The following is a brief history of the Second Revolution in the automobile industry, from *The Machine That Changed the World* (Womack, Jones and Roos 2007) as a prelude to a discussion of the Fourth.

1920 - 1950: Ford, Sloan, and Mass Production

Around 1910, Henry Ford saw inefficiencies in existing automobile manufacture and through mass-production was able to increase worldwide volume by a factor of 1000, to two million vehicles per year. In the late 1920's, Alfred Sloan of General Motors improved economic efficiency by measuring only a short list of financial metrics, including earnings, revenue, inventory, and market share. In the coming decades, nearly all industries adopted these approaches.

The automobile was a boon to farming and brought increased food security throughout society; farmers used tractors to grow more crops, and vehicles to ship them to distant markets. During World-War Two auto plants manufactured Jeeps and airplanes; following the war the expanding U.S. economy allowed millions of Americans to move off farms and into cities. As availability to food and conveniences became more secure, new technologies emerged and led to growth in many new fields like electronics, entertainment, and education.

1950-2000: Lean Management

As cities grew, traffic increased to become 'gridlock' and city dwellers moved to the suburbs. New houses included two-car attached garages, fast-food restaurants with drive-through service, suburban shopping malls and "Big Box" stores with acres of available parking. Highways widened and lengthened to help suburban dwellers attend city events and drive to other cities. The human footprint expanded, breaking up the wilderness. Fossil fuel consumption increased, and the planet's atmosphere warmed.

In the 1950's, Taiichi Ohno developed "Lean" methods at Toyota which, combined with rising labor costs, led corporations to develop supply chains in lower-cost markets around the world. In their 2016 book, *The Butterfly Defect* (Goldin and Mariathasan) discuss:

> "Toyota was the first company to recognize that by leaving the production of individual parts to specialty suppliers they could optimize efficiency and operate more cost effectively. This quest for efficiency moved Toyota to open manufacturing facilities worldwide. The firm overcame geographic, linguistic, and cultural barriers to search out the most cost-efficient locations balancing production costs, speed to market, and access to labor. Lean Management has become the ubiquitous driving principle of globalized production."

Many companies, many industries, and many nations joined the "global value chain", and world-wide societal value increased:

> "The spreading of new technologies and systems around the world led to immense changes in how human beings interact and what they may achieve. Poor people have benefitted most; no era in human history has seen such a rapid reduction in the number of people in dire poverty, and the chances that the individual born into a poor family can escape poverty and live a long and healthy life are greater than at any point in history."

2000-2019: China's Growth in International Trade

As the Cold War ended, Chinese Premier Deng Xiaoping launched an economic revolution, opened his country to world markets, and saw an eight-fold increase in exports from 1999 to 2008. Wuhan, China saw benefits in joining the global value chain.

From the (Wikipedia entry on Wuhan, China):

> "Prior to the 21st century, Wuhan was largely agricultural, but since 2004 has been a focal in the "Rise of Central China Plan", which aims to build less-developed inland economies into hubs of advanced manufacturing.
>
> "The automobile industry is dominant in the region. There are 5 car manufacturers, including Dongfeng Honda, Citroen, Shanghai GM, DFM Passenger Vehicle Dongfeng Renault and Dongfeng-Citroen headquartered in the city. By 2016, Wuhan attracted foreign investment from over 80 countries, with nearly 6,000 foreign-invested enterprises in the city injecting $22.45 billion in investment. "

The region grew to include 19 million residents, has 35 higher educational institutions, an airport serving 20 million passengers, and is a hub in the nationwide high-speed train system. It expanded to accommodate growth in the global automotive value chain, and like every other modern economic hub has transportation systems which allow people (and their infections) to move quickly around the world.

2020 and Beyond: A Systemic Pandemic

Steven Soderbergh's 2011 film *Contagion* is the hypothetical story of a viral pandemic. In one scene, bulldozers knock down trees which scatter some bats, who fly above a pigsty and drop a half-eaten banana. A pig eats the banana, is slaughtered, taken to a hotel kitchen, and Gwyneth Paltrow's character picks up the virus in a chance encounter with the chef. The following day she flies to Chicago and infects the entire U.S. Early parts of the movie are highly analogous to the first weeks of the COVID-19 pandemic.

The region of southern China, Vietnam, Myanmar, and Laos are home to bats which for millions of years have hosted 'reservoirs' of coronaviruses, including SARS-Cov-1, which jumped to humans near Guangdong in 2003, and SARS-CoV-2, which jumped near Wuhan in 2019. Hundreds of millions of people are in proximity to highly mobile bats (Mckenna 2020). Bats are particularly suitable hosts for viruses; their ability to fly allows them to control the inflammation which would afflict most mammals, and they become a near-perfect vehicle by which a viral reservoir can grow. Bats are not debilitated by the virus and can travel over one hundred kilometers a year.

Infected humans on airplanes outperform bats in term of viral spread. In previous centuries, endemics remained limited to a few thousand kilometers and would die out over time as humans developed immunity, but inter-continental travel is now easily available, and viruses can travel around the world in hours. SARS-CoV-2 (the *virus* which causes the COVID-19 *disease*) jumped to humans in December 2019 and infected all the world's ice-free continents by the following March.

Settling the Biomes

In 1700, the one-billion humans living on the planet used only 5% of its ice-free surface, but over the next three centuries the population doubled three times (to eight billion) and leaves only a quarter of the surface as wild. (Ellis 2010). While this chapter reflects primarily on the impacts of infectious viruses, it is inaccurate to view microscopic pathogens as the only threat. Aligned with the growth in globalization is the transmission of invasive species, such as:

- The **Emerald Ash Borer**, an inconsequential insect in its native region of north-eastern Asia has caused over $10B in damage in the U.S. Midwest and continues to spread. They likely arrived via shipping crates to Canton, MI. (Wikipedia: Emerald Ash Borer)

- **Zebra Mussels** are native to Russia and The Ukraine where they attached to ship anchor chains and have become invasive in the U.S. and Northern Europe. They are believed to be the source of an avian botulism which kills birds in the Great Lakes, responsible for the near extinction of many species, and lead to millions of dollars per year in cost to power plants and other water-consuming facilities. (Wikipedia: Zebra Mussel)

- The **Spotted Lanternfly** is native to China, India, and Vietnam but is now invasive in South Korea and the Delaware Valley of the U.S. It consumes over 70 plant species, including grape vines, fruit trees, and hardwoods like maple and birch. Per the USDA: *"If allowed to spread in the United States, this pest could seriously impact the country's grape, orchard, and logging industries."* (USDA: Spotted Lanternfly)

In the century past, which spans the Second Revolution, humans repurposed the wild, unintentionally living in ever-closer proximity to viruses and infections which they bring (Thomas 2020). Previously, threats to humans were lions, tigers, and bears, but expansion has now led to loss of habitat for these apex predators who would keep bats, birds, and rodents (and the reservoirs within) at bay. Humans have also developed technology to move great distances in short times, quickly expanding what were once local reservoirs to all of the world's continents.

Viruses mutate and evolve, and while thousands are catalogued millions are not. Sea-borne viruses increase oceanic respiration which reduces atmospheric carbon dioxide by 3 gigatons (Wikipedia: Viruses) per year, counteracting the 42 gigatons (McCarthy 2019) currently emitted by industrial society, meaning that they mitigate climate change. They are both beneficial and detrimental to human existence and more to the point are an innate part of an environment in which humans must exist.

Pandemic frequency is increasing as humans encroach upon reservoirs, and humanity is on the cusp of a change not seen since the introduction of mass production a century ago. We should expect the 21st century to be a Pandemic Age.

Systems Thinking and Economic Disruption

In 1920 (and especially 1720) the wilderness seemed infinite, and the environment capable of absorbing the small burdens that humans placed upon it, but by 2020, humans consume too much of the earth for environmental and social impacts to be trivial. A field of thought, known as "Systems Thinking", is well-

applied here, derived from two feedback loops described by Donella Meadows in her book *Thinking in Systems* (Meadows 2008), and Peter Senge in his, *The Fifth Discipline* (Senge 2006). They each quote the other, and Meadows developed her theories based on studies of nature.

In **Reinforcing Loops,** growth in an element *encourages* more growth, fed by other elements. In an avalanche, a snowball dislodged at the top of hill rolls, picks up snow and boulders, which in turn pick up more snow and boulders. The loop reinforces itself until it consumes all available resources, in this case when the avalanche buries the ski chalets at the bottom of the mountain.

In **Balancing Loops,** growth in an element is *counteracted* by other elements, until an equilibrium is found. We see this in the price sensitivity of commodities; as a product becomes more popular its price rises, which makes it and associated goods less popular. The sale of gas-guzzlers counteracts the price of oil; as oil prices climb, SUV sales fall, and vice-versa.

Systems Thinking highlights that individual actions have systemic effect; our actions *create* our reality. The pandemics we face are not malicious and external but are the summation of smaller independent actions. The past century of economic growth has brought a net gain in societal value (Goldin and Mariathasan 2014), but in the process placed burdens on environmental systems* which are now limiting human and economic growth. I'll discuss four such models.

Exponential Growth in Humans and Viruses

Reinforcing loops grow (and shrink) exponentially; a little growth makes a little more growth that much easier. In the Industrial Age, the introduction of the steam engine made life easier on humans, who used mechanization to grow more food and increase lifespans. This created opportunities for further innovation into mass production which made life easier still. The human population grew exponentially, as seen in Figure 2.

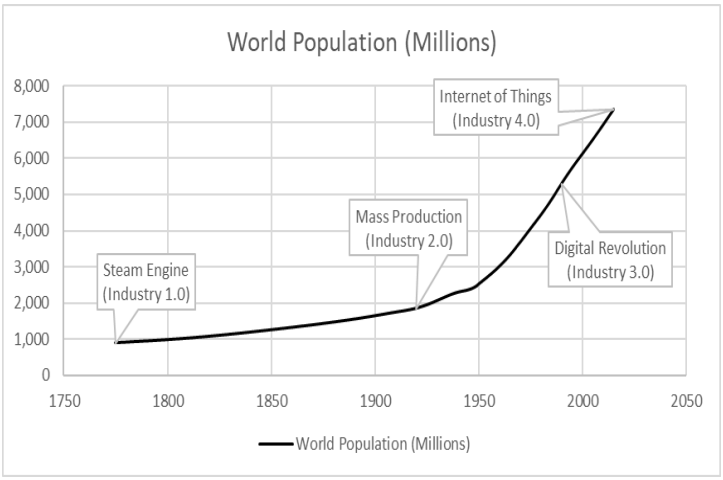

Figure 2: Population Growth in Industrial Age

A viral infection also grows and shrinks through systemic reinforcement. It originates as a tiny infectious agent which reproduces itself inside the cells of living hosts, at which point the host cell rapidly produces thousands of identical copies of the original virus. It may first grow within a bat, then a population of bats, then to a human (possibly vectored through an available pig, bird, or rodent), then within the

* And social systems, though these are beyond the scope of this chapter.

larger world-wide human population, and finally into the bats, birds, pigs, and rodents on new continents.

Limits to Growth Models

Biological populations grow until they either consume all available resources or face some opposing force, which is known as "Limits to Growth" model (Figure 3). In the reinforcing stage of the model, people infected today will infect more people tomorrow, increasing the *rate* of growth. Humans are social creatures with a need to interact, giving the viral reservoir an opportunity to grow. Eventually humans retreat from the virus, either by diminishing transmission (e.g., "social distancing") or diminishing susceptibility (a vaccine). Humans' neurological need to connect is balanced against the pathological risk of debilitating disease. As humans retreat, the reservoir diminishes. As the reservoir diminishes it seems safer to gather, and the reservoir grows. The number of active infections will rise and fall in waves.

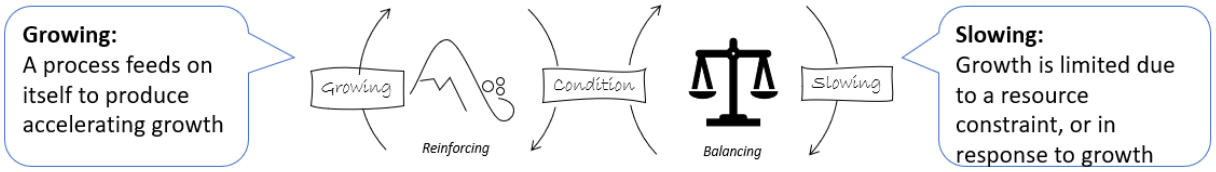

Figure 3: Limits to Growth

Figure 4 shows two such waves. The solid blue line is the sum of cases in New York, New Jersey, and Michigan, in which human hosts to the viral reservoir (aka "infected people") grew quickly in March and April, in which those three states alone for one-half of all U.S. infections, but limited viral growth through mandates and societal norms created a reinforcing decline. The dashed orange line sums all other states[†] and shows the effect of not controlling a reinforcing loop early. In late August, all states had slowed the growth of the viral reservoir, though infections in the "Other States" have increased as schools reopened.

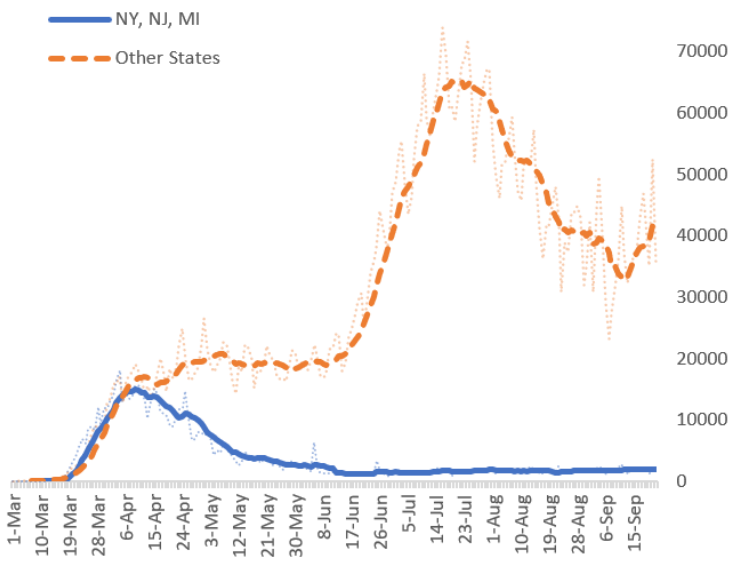

Figure 4: U.S Daily Cases
(New York Times Interactive: n.d.)

[†] As well as the District of Columbia, Puerto Rico, and Guam.

Shifting the Burden…

Senge describes a *"Shift the Burden"* model (Figure 5) where:

"An underlying problem generates symptoms that demand attention, but the problem is difficult to address because it is obscure or costly to confront. People "shift the burden" of the problem to other solutions – easy fixes which seem efficient.

Unfortunately, these easier solutions only address symptoms, leaving the problem unaltered. The problem gets worse though the symptoms apparently clear up, and the system loses whatever ability it had to solve the underlying problem."

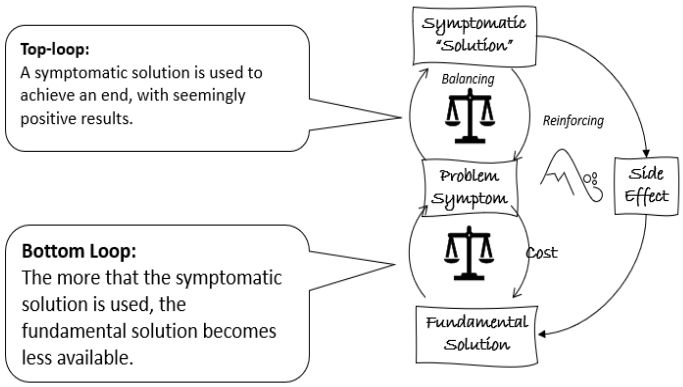

Figure 5: Shifting the Burden Model

From Figure 5 we can see two balancing loops; the bottom represents a fundamental solution (which will eventually be adopted) but is more time-consuming and costly than available symptomatic solutions. Choosing symptomatic over fundamental solutions becomes reinforcing, as they (seem to) address relevant issues at low cost. But in doing so, the fundamental solutions become ever more difficult to achieve. Eventually, side effects, leading the reinforcing loop to collapse upon the need for a fundamental solution.

Shifting the burden of manufacturing production onto a global value chain has brought humans in contact with novel viruses, leading first to world-wide increased prosperity, followed by a systemic public health collapse. Fundamental solutions will require a decreased risk of viral spillover from animals to humans and decreased world-wide transmission of viruses and invasive species. Eventually this will lead to localized supply chains, where conversion from raw material to usable product occurs close to the point of consumption, wherever it happens in the world. Regions should be prepared to produce all the products which they consume.

Following are three current examples of shifting production burdens:

… in Pharmaceutical Production

The Wall Street Journal reports (Yap 2020) on production of over-the-counter medications like acetaminophen, an inflammation reducer. A key ingredient is phenol, which American pharmaceutical makers produced in Texas and Louisiana until around 2000, at which point they shifted their attention to high-margin blockbuster drugs and shifted the burden of bulk pharmaceutical manufacture into China. That nation had had lower-cost chemists and manufacturing facilities, and now produces half of the world's active pharmaceutical ingredients (APIs), the ingredients in a pill that make it 'work'.

As SARS-CoV-2 expanded in China in January 2020, exports of acetaminophen to the U.S. declined by 70%. Chinese factories had closed due to employee quarantines or directed their production to meet local needs, and the U.S. saw supply shortages as the drugs were needed in the early stages of the pandemic.

Chinese exports picked up again in March and April, though one can make the case that this simply reinforces the symptomatic solution, making it that more difficult to develop what for U.S. local production of APIs. In the article, Christopher Priest of the U.S. Department of Defense states "The national security risks of increased Chinese dominance of the global API market cannot be overstated." As a vaccine is developed, the U.S., with one of the world's highest per capita rates of infections, should pay close attention to local availability of API's.

… in Masks

By July 2020, the head of the US Centers for Disease Control estimated that "the pandemic could be brought under control over the next four to eight weeks if we could get everybody to wear a mask right now" (McCabe 2020), at a time when the virus was known to be infecting 65,000 new patients per day.[‡] Imagine the value of even fewer masks at the time the pandemic was first identified in mid-March, when the new daily case rate was less than 1,000. Mask-wearing could have limited early growth of the viral reservoir and put it into a reinforcing decline. (For example, the New York, New Jersey, and Michigan chart in Figure 4)

Studies show that viral particles can "float" as an aerosol in closed spaces and permeate the entirety of a small room within minutes. A mask-wearing person (even a simple cloth mask) decreases aerosol spread. Masks are inexpensive, do not require months or years of research as is required of a vaccine, and have little in the way of negative side effects.

Medical staff use special "N-95" masks to protect themselves as they work in viral-laden environments, but these were in short supply in the early weeks of the U.S. pandemic. Lean management metrics used by hospitals encouraged low inventories and low unit cost, leading them to buy inexpensive masks from overseas "just in time". As with acetaminophen, by the early 2000's ninety percent of N-95 mask production had shifted to low-cost providers overseas. (Davis 2020)

In 2009, the company Prestige Ameritech was one of few remaining U.S. companies capable of manufacturing N-95 masks. The H1N1-09 "swine flu" pandemic was on the horizon, and Prestige increased production to meet the expected need, but that pandemic ended quickly, the market collapsed, and the company nearly went bankrupt. The symptomatic solution of purchasing from low-cost suppliers throughout the global chain was "working", in that the U.S. survived the 2009 swine flu and 2003 SARS-1 pandemics without the need for local mask production. There was no perceived need for a more fundamental solution.

In 2019, as SARS-CoV-2 appeared, Prestige again recognized the impending risk and reached out to the U.S. Department of Health and Human Services to seek funding to restart their 2009 production lines. (They did not want to face bankruptcy again.) But HHS did not follow through with an offer, Prestige's manufacturing capacity of 7 million masks per month remained idle, and medical staff were infected (in

[‡] CDC estimated that they are aware of only 10% of the actual infections, meaning that there may have been 650,000 new infections daily.

some cases fatally) in the early days of the U.S. pandemic. A new symptomatic solution appeared in late April as large manufacturing companies (including the automaker General Motors) began making masks and ventilator equipment. If the most fundamental solution to supplying N-95 masks to hospital staff is to minimize distribution risk, (e.g., manufacture the masks within the hospital) the U.S. still seems a long way off.

… in Management Theory

The "single-bottom-line" metrics of the airline, theme park, sports stadium, hotel, and restaurant industries (among others) all rely on a healthy populace, but they do not take on the burden of general public health. Had airlines invested hundreds of millions of dollars in manufacturing stockpiles of personal protective equipment, they might have saved hundreds of billions in lost revenues. Or they could have advocated for (and willingly paid) higher taxes so that sgovernment would take on the public health responsibility. Calling for higher taxes and/or supporting high inventories of hundreds of millions of unused masks (or mask-making equipment) seems financially inefficient for an airline, or any company in the travel and entertainment industry… except in comparison to the pandemic which they now face. This is not to fault past decision-makers, but to highlight the systemic nature of risk in running their companies based on mass, lean, and single-bottom-lines; the mainstays of the Second Industrial Revolution.

From *The Butterfly Defect*:

> The prevailing logic of supply chain management today is that the production of goods, where possible, should be outsourced to the most cost-efficient provider, and the homogenization of management education (in MBA programs) … cements the spread of practices like lean management and outsourcing.
>
> But it also leads to an over-reliance on a homogenized box-checking approach to risk management. As students in emerging Eastern Universities learn the techniques of their Westernized counterparts, and vice versa, it facilitates the spread of monocultures."

As industries and schools throughout the world align on a single set of practices, diversity of thought diminishes, and a monoculture develops. As all practitioners follow one approach, they become unable to recognize failures in that approach. The systemic failure in modern management theory is that it ***does not*** advocate for individual companies to demand increased public health spending.

The fundamental solutions to exit this Pandemic Age may be to:

- Diminish viral spillover by avoiding reservoirs and allowing wild spaces and apex predators to flourish.
- Minimize the transportation of pathogens and invasive species through reshoring supply chains.
- Increase the health of the public to recognize defend against new viruses and other biological invaders.

These will be discussed in the following section, but many industries should recognize that they will not restart until burdens are re-shifted.

Tragedy of the Commons

Donella Meadows supplies the following example in *Thinking in Systems*:

"Imagine a common pasture open to all herders. Each will try to keep as many cattle as possible in these commons, and will independently ask "what is the benefit vs. utility of me adding one more animal to my herd?" The benefit is the entire proceeds gained by one cow, while the cost of overgrazing is shared by all. The rational decision for each herder is to continue to add to their own herd, without regard to systemic collapse."

Senge diagrams this as in Figure 6. Organization's "A" and "B" each gain independently from their own activity, though the activities draw from a common depletable resource. Decisions made by "A" and "B" are locally rational, but eventually lead to systemic failure.

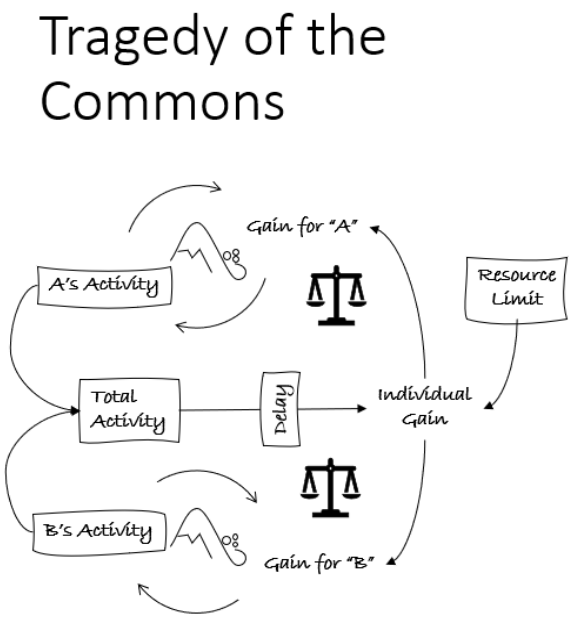

Figure 6: Tragedy of the Commons

… in Lobster Fishing

A historical example of this in lobster fishing off the coast of Maine (Mills n.d.), where each boat attempts to maximize its own catch, with the systemic result of depleting all available lobsters. Tragically, depletion of fisheries in the 1990's led to bankruptcies and economic suffering for not only the lobstermen, but the surrounding towns as well.

Through fisheries management lobsters came back to the coast of Maine (Maine.gov n.d.), and fishermen and governments developed cooperative mechanisms to limit individual activity in pursuit of maximizing regional goals. Maine is a popular tourist destination, and all businesses benefit when a steady flow of lobster is available. Local banks take on a systemic risk across the regional economy as they make loans to restaurants, hotels, and gift shops. While for each fisher it is economically rational to acquire as many lobsters as possible, for local banks it is rational to insist on sustainable practices in lobstering. The local economy is interconnected, and banks have the greatest visibility.

Global Investing to Manage Systemic Risk

In SARS-1 and SARS-2, the world suffers the fate of the Tragic Commons story. Mass, Lean, and single-bottom-line financial metrics led to industrialization near the habitat of viral-laden bats near hundreds of millions of people in southern China. Nearby airports accommodate millions of international passengers per year, and the infected unwittingly allow the viral reservoir to expand across continents,

pushing economies into recession. Industries have a common need for public health. Tragically, when thinking independently none has an economic rationale to invest in it.

Large institutional investors such as BlackRock, Vanguard, State Street, and CalPERS, with trillions under management, recognize that they are too big to avoid systemic risk. For example, BlackRock, the world's largest asset manager, announced in January 2020 (prior to COVID-19 reaching pandemic status) that it will make its investment decisions with environmental sustainability as a core goal. In the firm's annual letter to investors, CEO Larry Fink wrote: "The evidence on climate risk is compelling investors to reassess core assumptions about modern finance…", and "Awareness is rapidly changing, and I believe we are on the edge of a fundamental reshaping of finance". (Sorkin 2020)

A New Economy for the Fourth Industrial Revolution

Industry 2.0 enabled reinforcing economic growth, but this now faces limits as humans overlap with viral reservoirs. There have been multiple 21st century pandemics, we can expect more in the coming decade, thus putting us on the cusp of financial and technological changes known as the Fourth Industrial Revolution. The World Economic Forum, a '4IR' leader calls in its *Davos Manifesto 2020* for corporate purpose to expand beyond "shareholder capitalism" and towards "stakeholder capitalism", in which the corporation is "responsible to the Environment, Society and Good Government" (known as ESG). (World Economic Forum n.d.)

To date, there are no easy means to measure these important functions, but interested parties begin to align. In August 2019, 181 CEO's belonging to the Business Roundtable (such as GM, Boeing, Bank of America and BlackRock) signed a corporate governance agreement that *"moves away from shareholder primacy and includes a commitment to all stakeholders"* (Business Roundtable website, n.d.). Over 3,000 investment firms, representing $80 Trillion in assets under management, are signatories to the UN-backed Principles in Responsible Investing Initiative which *"acts in the long-term interests of the financial markets and economies in which they operate and ultimately of the environment and society as a whole"*. (Investopedia n.d.) (United Nations n.d.)

In January 2020 (just prior to the COVID-19 pandemic), the International Business Council, headed by the CEO of Bank of America, issued a similar statement to encourage discussion of proper metrics:

> "…it is important to consider environmental impacts along the full value chain (or 'lifecycle') of products or services. Individual businesses often operate in a small section of the overall value chain … but they rely on the continuing commercial viability of all upstream and downstream parts of the chain to sustain their own commercial success." (World Economic Forum n.d.)

To quote *The Butterfly Defect*:

> "The underlying threat of globalization on a systemic level pertains to the formation of harmonized structures and a failure to ensure 'resilience', the capacity of a system to absorb disturbance and reorganize while undergoing change"

Harmonized structures include businesses behaving in a Tragic Commons scenario, in which each act according to individual business metrics, without recognizing the larger systemic environment. Upstream and downstream risks cross industry and international boundaries in unexpected ways; while

Wuhan's economy developed to support the global automotive value chain, a nearby viral reservoir creates existential risk for the travel and entertainment industries. Century-old businesses now interconnect in ways unimaginable to their founders. To minimize systemic risk, we need new economic and industrial systems. A few are described here.

Supply Chain Visibility

Globalization has led to long and 'opaque' supply chains; where manufacturers buy components from 'first-tier' suppliers, who in turn buy sub-components from 'second-tier' suppliers, and on and on. Prior to the 2020 pandemic multinational corporations (MNCs) recognized systemic supply-chain risk and created standards for themselves and first-tier suppliers. They expected these to cascade down onto the lower tiers, but both the effect on, and visibility into, the chain is limited. In the March 2020 Harvard Business Review article "A More Sustainable Supply Chain":

> The aim to create a cascade of sustainable practices that flows smoothly throughout the supply chain is hard to realize in practice. Many of the corporations that have committed to it have faced scandals brought about by suppliers that, despite being aware of sustainability standards, have nevertheless gone on to violate them.
>
> Lower-tier suppliers often do not have sustainability expertise or resources, and they may be unaware of accepted social and environmental practices and regulations. They are frequently located in countries where such regulations are nonexistent, lax, or not enforced at all. And typically, they don't know much about the sustainability requirements imposed at the top-tier —and have no incentive to comply. (Villena and Gioia 2020)

Further, top-tier corporations handicap themselves through dysfunction and uncoordinated goals. They often don't know who or where their lower-tier suppliers are, let alone their capabilities. Sub-groups within the MNC make key decisions without sustainability or compliance in mind. From the HBR article:

> Top-tier engineering and procurement units often preapprove lower-tier suppliers, but their vetting criteria doesn't include social and environmental considerations… Not surprisingly, this leads to situations in which preapproved lower-tier suppliers violate the sustainability requirements of the top-tier consumers they work with.
>
> When we asked a representative at one supplier why his company had violated a 60-hour workweek limit, he gave us a frank explanation: "We didn't want to tell our customer that we can't produce its products on time, because otherwise it's going to try to find someone else that can. But our customer didn't give us enough notice to hire enough skilled people to do the job."

Engineering and procurement groups may have de facto authority to drive lower-tier purchasing decisions based on *unit* cost, without regards for *environmental* or *social* costs. This is a Tragic Commons scenario, where locally rational decisions lead to systemic sustainability failures.

Localizing Supply Chains

'Short' supply chains are less opaque and will become more valuable as nations become cognizant of the risk of transporting diseases and invasive species. In late August 2020, the U.S. averaged 13 cases per 100,000. Canada has one-tenth the per-capita rate of infection than does the U.S. and has closed its borders to foreign travelers. Hypothetically, when will Canada allow visitors, and how long can

corporations maintain buyer-supplier relationships if the former is unable to visit the factories of the latter? States and regions enforce 14-day quarantines upon entry, but what was formerly a 2-hour trip between Detroit, MI and Windsor, ON would in this scenario require 2-week quarantines on either side. Travel restrictions, whether government-enforced or through individual safety concerns, become sand in the gears of the worldwide economy.

Aircraft and automobiles include thousands or millions of parts from dozens of countries; if a U.S. auto assembly plant can't get tires from Brazil (possibly due to high infection rates), it won't need engines from Canada. The $20 Trillion U.S. economy imported over $3 Trillion in goods in 2018 (McBride and Chatzky 2019), much of which as componentry into larger goods. As import frictions rise, the lost opportunity due to unavailable components will increase. All industries leveraging a global value chain will face similar issues as discussed previously with N-95 masks and pharmaceuticals.

New Technologies

Early in the pandemic the United Nations researched supply shortages in ventilators, and how Industry 4.0 technologies might in the future provide relief:

> "One of the main bottlenecks in the current production of ventilators is the timely supply of components due to dependence on inputs produced by global suppliers. Instead of producing the entire product from scratch, countries specialize in different tasks resulting in high interdependencies. One of the leading manufacturers of ventilators declared that it would double its output (in weeks, but) it relies on its wide network of closely integrated global suppliers for continuing its operations, including timely production of electrical components such as circuit boards or sensors.
>
> "Industry 4.0 unlocks new labor-saving technologies which could potentially reduce reliance on low-skilled, low-cost labor in manufacturing. This has implications for the global geography of production, as value chains can be expected to become more regional in nature, moving closer to key final consumer markets in China, the European Union, Japan and the United States. Industry 4.0 is also likely to have an impact on the length of value chains, as automation could consolidate various steps of the value chain."
>
> "Several factors seem to support the argument that automation and possibly reshoring will accelerate following the COVID-19 pandemic. The case of testing in the Republic of Korea exemplifies that automation facilitates supply-side adjustments (e.g., through on-demand ordering), mitigating firms' risks in case of a pandemic or other shock, as it allows for more flexible adjustment to increasing demand. In an effort to reduce countries' dependence on global supply, industrial policies to secure the supply of goods deemed critical to the healthcare sector and national security could be implemented." (Seric and Winkler 2020)

The increased use of automation implies a need to upskill workforces, which is discussed shortly.

Digitalization and 'Pop-Up' Vaccine Factories

An important use of digitalization (discussed elsewhere in these proceedings) is in supporting the manufacture and distribution of vaccines and treatments when they are developed. The worldwide

potential for a COVID-19 vaccine is five billion or more units per year,[§] of a perishable and life-saving product. Vaccine doses require low temperature storage in addition to all the availability concerns discussed previously concerning masks and acetaminophen. Liquid doses will require either an injection or inhalation device, implying the need to manufacture, store, distribute, and dispose of large quantities of metal and plastic.

Rather than a few large, multi-billion dose factories a more fundamental solution will be to build smaller factories near population centers which consume the vaccine, syringes, and inhalers. If we arbitrarily assume one factory per fifty million people, it implies the need for 1000 vaccine production factories scattered throughout the world.

Digital Manufacturing Twins

In Henry Ford's time it made sense to assemble all of the world's automobiles in Detroit and transport them everywhere, because knowledge in how to manufacture thousands of cars per day was local to the region. But in the world of 4IR, we can transmit *digital information* about vaccine factories, rather than transport *physical products*. Modern industries design and simulate their products and factories using 3D virtual models, this can and should be applied to vaccine manufacturing.

The concept of a "Digital Twin" is that every physical thing inherently holds information about that thing, such as its size, mass, center of gravity, and chemical or electrical properties. If we want the information about, say, a desk we could use a ruler and a scale to measure length, width, and mass, but if we have the desk's original designs it is not necessary to make these measurements, we can simply look at the designs. In the past these might have been "ink on paper" blue prints, but modern products are developed using 3-dimensional software to establish dimensions, calculate mass, and simulate how the physical object will behave in the environment. The software can even determine how much mass the desk can hold before it collapses.

In this scenario, there is both a virtual instance of the desk (the 3D computer model), and the physical instance (the object in my office which holds my cup of coffee as I type this). These dual instances create a Digital Twin. (Grieves 2011)

A *Digital Manufacturing Twin* begins with the virtual instance of a manufacturing plant (much like the virtual desk). The factory would be replicated in a thousand locations around the world in order to manufacture vaccines locally for nearby populations of around 50 million people. Each of the thousand physical plants could be identical, as they are based on the same virtual model.

An example currently exists in two Siemens electronics plants, one in Amberg, Germany and the other in Chengdu, China:

> "We mapped the processes from the Amberg plant to Chengdu on a 1:1 basis," explains Dr. Gunter Beitinger, who is responsible for Siemens' Digital Factory Business Units in Amberg, Fürth and Chengdu. From its machinery and software tools to its execution system which records and controls every aspect of the production process from start to finish at a virtual level,

[§] The math: The human population in 2020 is about 7.8 billion. There many unknowns, including duration of immunity, the percentage of recovered or inoculated people required for herd immunity, and the number of doses per year needed for inoculation. If 70% of the world needs one dose per year, it's roughly 5 billion doses.

the equipment in Chengdu is designed on the same principles and processes as the equipment at the Amberg factory. (Siemens Corp. n.d.)

To greater and lesser extent, aircraft manufacturers have adopted digital twin strategies (earlier in my career, I helped them with this). As the airline industry will not recover until the development of either a vaccine or a treatment, aircraft manufacturers might explore new business units around the design and build of vaccine manufacturing plants.

Impact on Workforces

A pre-pandemic 2018 study by (The Manufacturing Institute n.d.) shows that the U.S. will need 15 million skilled manufacturing workers to meet manufacturing needs a decade later, and only ten million people of the future workforce were members of the 2018 workforce. Further, the 'advanced' manufacturing skills of the Fourth Revolution become quickly obsolete, with only 50% of technical skills still relevant after five years. This implies that of the 10 million workers in 2028 who will have a decade or more experience, only 25% of what they knew in 2018 will still be relevant. Of the remaining five million positions, only 2.4 million will find workers with the necessary skills; the remaining 2.6 million advanced manufacturing positions will go unfilled for lack of workers with the necessary skills.

And this was prior to the need to re-shore supply chains build vaccine factories.

This follows a "Shift the Burden" model, in which the burden of manufacturing the world's goods moved to low-cost regions, and the U.S. no longer has workers with necessary skills. As industries re-shore supply chains, there will be increased demand for flexible workforces skilled in automation. Businesses must actively focus on creating and improving skills in their current and future workforce if they hope to survive. Among other goals, tuition burdens for post-secondary education will need to shift from students and their parents to employers.

Viral Monitoring

To decrease viral spillover, we must repopulate apex predators into the wild and increase the buffer between humans and viruses. But we must also assume that some of the millions of unknown viruses will continue their jump to humans. Limiting early growth can stop viruses before they impact humanity.

IoT Thermometers

The "Internet of Things" is a large and growing concept that non-computers ("things") might be connected to the internet. The company Kinsa, sells thermometers which connect to the user's cell phone, and from there to the internet.

Fever is a potential symptom of COVID-19, and when people feel sick, they take their temperatures with Kinsa thermometers. The company collects this and posts anonymized fever data to a "health map" on their website, healthweather.us. and can predict when flu-like illnesses will appear about a week before patients call their doctors.**Error! Reference source not found.** In this scenario the number of feverish people in a region could call for localized lockdowns (rather than state or county-wide lockdowns). As it becomes the norm to have one's temperature taken upon entering a building, this can provide an important source of data.

(Note that body temperature is not conclusive; recent evidence shows that asymptomatic carriers of the SARS-CoV-2 virus do not have fevers. But we should prepare for more viruses.)

Sewage Monitoring

From the UK's Centre for Ecology and Hydrology: (Williams 2020)

> *"Scientists will develop a standardized UK-wide system for detecting coronavirus in wastewater, to provide an early warning of future outbreaks and reduce reliance on costly testing of large populations.*
>
> *"Several studies have shown that the RNA of SARS-CoV-2 - the genetic material of the virus - can be detected in wastewater ahead of local hospital admissions, which means wastewater could effectively become the 'canary in the coal mine' for COVID-19 and other emerging infectious diseases.*

American Universities are following similar methods. R.I.T, in Rochester, New York, and the University of North Carolina, Charlotte are collecting samples from residence sewage lines. Automated means of testing samples are on the near horizon.

Similar to the IoT Thermometers, sewage monitoring could provide localized recognition of this and future viruses. Sewage has an advantage over the thermometers in that it can recognize the virus in a population which does not feel sick enough to take their temperature.

Individual Testing

Sewage monitoring and in-home temperature collection can identify communities in which the virus exists, to be followed by individual testing. South Korea accomplished this at mass scale in, as reported by the United Nations Industrial Development Organization (UNIDO) (United Nations Industrial Analytics Platform 2020):

> *"[South] Korea is using Industry 4.0 technology to test far more people for COVID-19 than has been possible in many other countries and has thereby successfully limited the number of deaths linked to the virus. The Korean company Seegene, which carries out multiplex molecular diagnostics, relied on its artificial intelligence-based big data system to develop a test for COVID-19 within a few weeks, a procedure that usually takes several months to complete. Quick approval by the Korea Centers for Disease Control and Prevention within less than one week ensured that testing for COVID-19 was up and running. Moreover, Seegene's system uses automatic testing, i.e. samples are analyzed by a diagnostic machine rather than by humans, which speeds up the process and reduces risk of error and contamination."*

Conclusion

I was on a weekly, family Zoom call recently, which included two family members who each live near Seattle. In two families, three of their college-age kids had been forced home from Florida, Wisconsin, and California due to COVID-19, and are now "attending" classes remotely, with no obvious end in sight. Further no one in either family is able to walk outside of their Seattle homes due to smoke from fires which are burning hundreds of miles away, and likely to last for weeks. (And recur yearly.)

Is this the society that we want?

The next 10 years, especially the next 24 months, will see a rapid change, particularly towards the environment. Trillion-dollar asset managers are recognizing that a century of Industry 2.0 has created a

systemic and catastrophic risk, and placing new investments in industries dependent on carbon emissions will lead the asset managers to further losses in fire damage, sea rises, and pandemics. The most rational economic position of these firms is to is to shift their investment focus from shareholder to societal value, and they are doing this. I envision economic incentives shifting from products consumers want to buy, to those in which asset managers are willing to invest.

I teach a graduate course in Engineering Management and my students are millennials born around 1990. They were graduating high school as financial markets collapsed in 2009 and would like to buy houses and plan families as the COVID-19 recession appeared in 2020. The World Bank predicts the global economy to shrink by more than 5% in this year, and the U.S. posted its worst unemployment figures ever in Q2-2020. In financial crises over the past two centuries, it has taken a median of seven years for per-capita GDP to return to pre-crisis levels. (Reinhart and Reinhart 2020) Millennials also face high student loan debt, and the increasing impacts of climate change. (Do NOT underestimate Greta Thunberg.) For their own security and to improve their quality of life they will search for new economic means by which they measure success.

In spite of (or maybe because of) these challenges I see in my students a group who will transform industry and economy in ways not seen in the century since Henry Ford. Our current decade is not starting at all well, but I expect by its end we will see a strong advancement into new measures of industry and economy, based on the triple bottom lines of People, Planet, and Prosperity.

References

Business Roundtable website,. n.d. Accessed Sep 3, 2020. https://www.businessroundtable.org/business-roundtable-redefines-the-purpose-of-a-corporation-to-promote-an-economy-that-serves-all-americans.

Maine.gov. n.d. *A guide to lobstering in Maine.* Accessed September 3, 2020. https://www.maine.gov/dmr/science-research/species/lobster/guide/index.html#management.

n.d. *New York Times Interactive:.* New York Times Company. Accessed 2020. https://www.nytimes.com/interactive/2020/world/coronavirus-maps.html.

Tankersley, Jim, and Ben Casselman. 2020. ""A Resurgence of the Virus, and Lockdowns, Threatens Economic Recovery"." *NY Times.com.* July 15. https://www.nytimes.com/2020/07/15/business/economy/economic-recovery-coronavirus-resurgence.html?referringSource=articleShare.

2020. ""Air travel's sudden collapse will reshape a trillion-dollar industry."." *The Economist.com.* August 1. https://www.economist.com/business/2020/08/01/air-travels-sudden-collapse-will-reshape-a-trillion-dollar-industry.

2019. ""How Much of Airlines Revenue Comes from Business Travelers?"." *Investopedia.* July 15. https://www.investopedia.com/ask/answers/041315/how-much-revenue-airline-industry-comes-business-travelers-compared-leisure-travelers.asp.

Cameron, Doug. 2020. ""United plans to Cut more than 16,000 Staff"." *The Wall Street Journal.* September 2. https://www.wsj.com/articles/united-plans-to-cut-more-than-16-000-staff-11599061023.

Conger, Kate, and Erin Griffith. 2020. *"The results are in for the sharing economy they are ugly." Published 2020-05-07.* 5 7. Accessed 2020. https://www.nytimes.com/2020/05/07/technology/the-results-are-in-for-the-sharing-economy-they-are-ugly.html.

Davis, Aron C. 2020. "In the early days of the pandemic, the U.S. government turned down an offer to manufacture millions of N95 masks in America." May 9. https://www.washingtonpost.com/investigations/in-the-early-days-of-the-pandemic-the-us-government-turned-down-an-offer-to-manufacture-millions-of-n95-masks-in-america/2020/05/09/f76a821e-908a-11ea-a9c0-73b93422d691_story.html.

Ellis, E.C. et. al.,. 2010. "Anthropogenic transformation of the biomes, 1700 to 2000." *Global Ecology and Biogeography,.* http://ecotope.org/people/ellis/papers/ellis_2010.pdf.

Goldin, Ian, and Mike Mariathasan. 2014. *The Butterfly Defect: How Globalization Creates Systemic Risks and What To Do About It.* Princeton: University Press.

Grieves, Dr. Michael. 2011. *Virtually Perfect: Driving Innovation and Lean Products Through Product Lifecycle Management.* Cocoa Beach, FL: Space Coast Press.

Investopedia. n.d. *UN Principles of Responsible Investing.* https://www.investopedia.com/terms/u/un-principles-responsible-investment-pri.asp.

McAloose, Denise et.al.,. 2020. "“From people to Panthera: Natural SARS-CoV-2 infection in tigers and lions at the Bronx Zoo.”." July 24. https://www.biorxiv.org/content/10.1101/2020.07.22.213959v2.

McBride, James, and Andrew Chatzky. 2019. "The U.S. Trade Deficit: How Much Does It Matter?" March 8. https://www.cfr.org/backgrounder/us-trade-deficit-how-much-does-it-matter.

McCabe, Caitlin. 2020. "Face Masks Really Do Matter. The Scientific Evidence Is Growing." August 13. https://www.wsj.com/articles/face-masks-really-do-matter-the-scientific-evidence-is-growing-11595083298.

McCarthy, Joe. 2019. "Greta Thunberg Understands the ‘Carbon Budget’—do you?" *Global Citizen.* September 24. https://www.globalcitizen.org/en/content/what-does-a-carbon-budget-mean/.

Mckenna, Maryn. 2020. "The Virus Hunters." *Smithsonian Magazine.* July 20. https://www.smithsonianmag.com/science-nature/scientists-hunt-viruses-animals-before-strike-humans-180975081/.

Meadows, Donella H. 2008. *Thinking In Systems.* White River Junction: Chelsea Green Publishing.

Mills, Kathy et. al. n.d. *“Resilience, Adaptation, and Transformation in Lobster Fishing Communities”.* Gulf of Maine Research Institute website. Accessed September 3, 2020. https://www.gmri.org/projects/resilience-adaptation-and-transformation-lobster-fishing-communities/.

Reinhart, Carmen, and Vincent Reinhart. 2020. "The Pandemic Depression." *Foreign Affairs.* September. https://www.foreignaffairs.com/articles/united-states/2020-08-06/coronavirus-depression-global-economy.

Schwab, Klaus. 2015. "“The Fourth Industrial Revolution. What It Means and How To Respond.”." *Foreign Affairs.* December 12. https://www.foreignaffairs.com/articles/2015-12-12/fourth-industrial-revolution.

Senge, Peter M. 2006. *The Fifth Discipline.* New York: Currency.

Seric, Adnan, and Deborah. Winkler. 2020. "Managing COVID-19: Could the coronavirus spur automation and reverse globalization?" April. https://iap.unido.org/articles/managing-covid-19-could-coronavirus-spur-automation-and-reverse-globalization.

Siemens Corp. n.d. *A Digital Manufacturing Lighthouse.* Accessed Sep 3, 2020. https://new.siemens.com/global/en/company/stories/research-technologies/topics/digital-factory-siemens-electronic-works-chengdu.html.

Sorkin, Andrew Ross. 2020. "BlackRock C.E.O. Larry Fink: Climate Crisis Will Reshape Finance”." February 24. https://www.nytimes.com/2020/01/14/business/dealbook/larry-fink-blackrock-climate-change.html.

Tara, Roopinder. 2020. ""“The Old Warhorse Passes the Unicorn – Microsoft Teams Winning Corporate Collaborators.”." *Engineering.com.* June 30. https://www.engineering.com/DesignSoftware/DesignSoftwareArticles/ArticleID/20469/The-Old-Warhorse-Passes-the-Unicorn-Microsoft-Teams-Winning-Corporate-Collaborators.aspx.

The Manufacturing Institute. n.d. *Skills Gap and Future of Work Study 2018.* Accessed Sep 3, 2020. https://www.themanufacturinginstitute.org/research/2018-deloitte-and-the-manufacturing-institute-skills-gap-and-future-of-work-study/.

Thomas, Liji. 2020. "Human encroachment into forest land caused bat CoV spillover and COVID-19 emergence." *News-Medical.Net.* August 31. https://www.news-medical.net/news/20200806/Human-encroachment-into-forest-land-caused-bat-CoV-spillover-and-COVID-19-emergence.aspx.

United Nations Industrial Analytics Platform . 2020. "Managing COVID-19: Could the coronavirus spur automation and reverse globalization?" April. https://iap.unido.org/articles/managing-covid-19-could-coronavirus-spur-automation-and-reverse-globalization.

United Nations. n.d. *Principles of Responsible Investing.* Accessed Sep 3, 2020. https://www.unpri.org/signatories/signatory-resources/signatory-directory.

n.d. *USDA: Spotted Lanternfly.* https://www.aphis.usda.gov/aphis/resources/pests-diseases/hungry-pests/slf/spotted-lanternfly.

Villena, Verónica H., and Dennis A. Gioia. 2020. ""“A More Sustainable Supply Chain”." March. https://hbr.org/2020/03/a-more-sustainable-supply-chain.

n.d. *Wikipedia entry on Wuhan, China.* https://en.wikipedia.org/wiki/Wuhan.

n.d. *Wikipedia: Emerald Ash Borer.* https://en.wikipedia.org/wiki/Emerald_ash_borer.

n.d. *Wikipedia: Viruses.* https://en.wikipedia.org/wiki/Introduction_to_viruses.

n.d. *Wikipedia: Zebra Mussel.* https://en.wikipedia.org/wiki/Zebra_mussel#North_America.

Williams, Simon. 2020. *Work begins on UK system for estimating COVID-19 cases from wastewater.* July 2. https://www.ceh.ac.uk/press/work-begins-uk-system-estimating-covid-19-cases-wastewater.

Womack, James, Daniel T Jones, and Daniel Roos. 2007. *The Machine That Changed the World,.* New York: Simon & Schuster.

World Economic Forum. n.d. Accessed Sep 3, 2020. http://www3.weforum.org/docs/WEF_IBC_ESG_Metrics_Discussion_Paper.pdf.

—. n.d. "Davos Manifesto 2020: The Universal Purpose of a Company in the Fourth Industrial Revolution." Accessed September 3, 2020. https://www.weforum.org/agenda/2019/12/davos-manifesto-2020-the-universal-purpose-of-a-company-in-the-fourth-industrial-revolution.

Yap, Chuin-Wei. 2020. "Pandemic Lays Bare U.S. Reliance on China for Drugs." August 5. https://www.wsj.com/articles/how-the-u-s-ceded-control-of-drug-supplies-to-china-11596634936.