Exponential Age (Azeem Azhar, 2021)

The Exponential Age has 2 key strands. 1st, new technologies are being invented and scaled at an ever-faster pace, all while decreasing rapidly in price. 2nd, our institutions—from our political norms, to our systems of economic organization, to the ways we forge relationships—are changing more slowly. The result is what I call the "exponential gap": the chasm between new forms of technology—and the corporations, employees, politics, and wider social norms that get left behind. Our age is defined by the emergence of several new general purpose technologies (GPTs), each improving at an exponential rate. Human-built institutions are slow to adapt, from the psychological difficulty of conceptualizing exponential change to the inherent challenge of turning around a big organization. If the story of the industrial age was of globalization, the story of the Exponential Age will be relocalization.

Exponential technology proved its mettle with COVID-19. Moore's Law is not predictive; it is descriptive, a "social fact." An exponential increase is anything that goes up by a constant proportion. An exponential technology improves at roughly a fixed cost, at a rate of more than 10%/year for several decades; more than 2.5 times more powerful for the same price every 10 years; or costs drop by more than 60%. This change should hold true for decades. As the price of a technology drops, it starts to crop up everywhere. Industry can suddenly afford to bundle exponential technologies into new products. They lead to continually cheaper products able to do new things. The spread of most technologies follows an S-curve. The pattern of general uptake looks like a lazy "S."

Smartphones diffused 12.5 times faster than the original telephone. Hyperdeflation creates ever-greater possibilities. The construction costs of semiconductor fabs have increased at about 13%/year—the most recent cost $15b or more to build. Moore's Law is being derailed by quantum-drunk electrons. The exponential march of technology is not about the straightforward progression of individual inventions. The illusion of continual exponential technological development is from dozens of different technologies developing in tandem and continually interacting. At any one time there are multiple technologies following an S-curve. As one S-curve reaches its highest gradient, another curve begins. Once our 1st curve starts to flatten out, the younger technology is approaching the explosive phase of its acceleration—and takes up the mantle of rapid growth. Innovations in one sector inspire developments in the next. The result is that, across society, there is a quickening in the pace of technological progression—even if development of individual technologies is consistently slowing down.

There is a new technical paradigm: artificial intelligence (AI). It catalyzed a wholly new way of thinking about computing power. A computer can be considered intelligent if it is able to take actions that can achieve its objectives. A piece of AI software needs to be able to make some kind of decision. "Machine learning" is a method that involves gathering huge amounts of information about a problem and using algorithms to identify recurrent patterns. This approach needs masses of information and expensive computation. New neural networks contained 650,000 neurons and 60 million parameters, settings you could use to tune the system. Scientists rushed to build artificial intelligence systems, applying deep neural networks and their derivatives to a vast array of problems, from spotting manufacturing defects to translating between languages; from voice recognition to detecting credit card fraud; from discovering new medicines to recommending the next video we should watch.

Investors opened their pocketbooks eagerly to back these inventors. In short order, deep learning was everywhere. Between 2012 and 2018, the amount of computer power used to train the largest AI models increased about 6 times faster than the rate of Moore's Law. The calculations that video games needed to produce realistic scenes involved a lot of multiplying. To get a sophisticated neural net to work, you'd need to perform millions, sometimes billions, of such multiplications—and graphics chips were up to the task. AI developers needed more power, and that power would come from specialist chips, chips suited for one task alone: running neural networks at high speeds.

This means that computing power looks set to grow exponentially for the foreseeable future. Unlike the binary nature of bits, which must either be a 0 or a 1, a qubit can represent all values between 0 and 1 simultaneously. Quantum computers are not suitable for most types of computation, but they can tackle vital problems. This is all about modeling new kinds of molecules. In some kinds of modeling the quantum computer was more than 1 billion times faster than its classical rival. Computing was the harbinger for the Exponential Age, the 1st technology to exhibit this remarkable rate of change.

Between 1975 and 2019, photovoltaics dropped in price some 500 times—to under $0.23/watt of power. The cost of solar power has been declining at exponential rates—about 40%/year. In the decade up to 2019, the price of electricity generated by solar power had declined by 89%. Solar power has become the cheapest source of electricity in 2/3 of the world. Exponentiality has become widespread in 4 key domains of technology, which form the bedrock of the global economy--computing, energy, biology, and manufacturing. The costs of the key technologies in each are falling dramatically, by a factor of 6 or more every decade.

Every new innovation interacts—and combines—with the others to create new technological possibilities. All the while, growing networks of information and trade make the spread and scaling of new technology easier by the day. In the 10 years to 2019, the cost of generating electricity from wind turbines declined by 70%, or about 13%/year. Batteries are on an exponential trajectory too. The cost of lithium-ion storage dropped by 19%/year for the decade from 2010. As of 2021, large-scale battery systems are nearly cheap enough to compete with coal- and gas-fired power stations.

The 1st complete human genome was sequenced between April 1999 and June 2000. The cost of the 1st draft of our genetic script was about $300 million. To decode that 1st genome cost at least $500 million, and possibly as much as $1 billion. By August 2019, that price had declined to $942, a 100,000 times improvement. By March 2020 a full genome cost only $100—representing a million times improvement in less than 20 years. That equates to a halving in price every year for 2 decades. Genome sequencing has fallen a 1000 times further than Moore's Law would have forecast.

There have been developments in the way we produce the reagents and "amplifiers" required to turn a DNA sample into something readable. These chemicals have become progressively cheaper and cheaper. Cheaper sensors, and developments in robotics have allowed for more automation of the manual parts of the convoluted process. With synthetic biology, a field that melds several disciplines, including computer science, biology, electrical engineering, and biophysics, we can sequence and manipulate microorganisms. We can turn them into little natural factories to produce the chemicals and materials we need.

60% of the physical inputs in the global economy may be produced biologically by 2040. 3D printing (additive manufacturing) methods are developing at a pace of between about 37%/year. The 3D printing market grew 11 times in the decade to 2019—a rate of 27%/year. Narrow technologies can have a broad impact. The humble stirrup is credited with helping Genghis Khan sweep across Asia to create the world's largest land empire. The light bulb broke us free from the shackles of darkness.

However, throughout history GPTs have transformed society beyond recognition. Electricity drastically altered the way factories work and revolutionized our domestic lives. The printing press played a key role in the European Reformation. GPTs change almost everything in a society by creating an agenda for the creation of new products, new processes, and new organizational forms. We are witnessing the emergence of a transformative new wave of GPTs like the early 20th century's offering of the telephone, the car, and electricity. GPTs take a while to have meaningful effects—as new infrastructure is built, ways of working change and companies train their employees in these novel practices.

GPTs are integrated into the economy in a series of steps--the installation phase, deployment phase, complementary services, like repair and supply shops, are established. Societies enjoy the boons of a GPT in a "golden age." Much of the infrastructure—think cloud computing and smartphones—has already been deployed. The transformation may come faster than in any previous era. Our age is defined by the cascading of technologies: one new technology leads rapidly to the next, and to the next.

3 forces drive the exponential revolution: The 1st is learning by doing. If we stopped endeavoring to make Moore's Law true, it would cease to be true. It is ill-equipped to explain why technologies improve. Wright's Law: For every doubling in units produced, costs fall by 15%--otherwise known as the "learning rate." The key to Wright's Law is increasing volume. Wright's emphasizes the relationship between demand and skill. Researchers have discovered that his law applies to dozens of technologies—from the outputs of the chemical industry to wind turbines and transistors. Wright's Law more accurately describes what happened to silicon chip prices than Moore's Law does. Market saturation is much more distant—because global markets are so much larger. In the last 50 years the volume of world trade increased 60 times, from $318 billion to $19,468 billion in 2020. And this pushed us ever further down the path of Wright's Law. Technological progress takes on its own momentum: the more we make of something, the more demand there is, and so the more we make. We learn by doing. And in recent years, we have been doing more. Eventually, that resulting process tipped us over into the Exponential Age.

The 2nd driver is combination. not only improving at exponential rates, but combining in novel and powerful ways and by standardization. International standards bodies build consensus around simple things (like components) and complex things (like manufacturing processes). The most important standards of the Exponential Age have been developed from the bottom up, often by the very people who are creating new technologies. And we all benefit hugely from that interoperability. Standardization of this kind makes the world more efficient—and allows different innovations to combine. Combination and recombination catalyzes further innovation. Companies count cars in shopping-mall parking lots to estimate customer demand, and assess how well the retail sector is doing. Or they analyze the shadows cast by oil tankers to estimate their load—and hence the global demand for oil. Standard components have made satellites more affordable and space more accessible. In software, standardization has become commonplace, easy-to-access lumps of code.

The 3rd driver of exponential technology: the profusion of networks. Networks have changed the nature of trade, invention, science, relationships, disease, finance, information, threats, and more. The "open access" movement seeks to widen the availability of scholarly thinking. In December 2019, 23 million scholarly papers were downloaded across all disciplines on preprint servers. BioRxiv was launched for biologists in 2003, and both PsyArXiv for psychologists and SocArXiv for the social sciences launched in 2016. GitHub lets 56 million software developers collaborate across 60 million different software projects. These information networks catalyze the emergence of exponential technology. While informational networks help ideas spread worldwide, the shipping container does the same for physical products. In the 1950s moving goods from the US to Europe or vice versa might take 3 months, and shipping costs might run to 20% of the cargo's value. Containerization changed all that (8 feet wide, 8½ feet high, and 10, 20, or 40 feet long). By 2020 the world's largest container ship, the HMM Algeciras, fully laden, could hold 23,964 of the boxes. Between 1980 and 2015, the global capacity of container ships worldwide grew 25 times. Between the end of World War II and 1980, sea-freight costs declined 2.5 times. Over the subsequent 30 years, prices would halve again. Huge behemoths like Apple hold fewer than 10 days of stock. It can rely on the digital network of the internet to take the order and coordinate it, and a physical network of trucks and ships to meet all foreseeable demand. Exponential technologies are being driven by 3 mutually reinforcing factors—the transformative power of learning by doing, the increasing interaction and combination of new technologies, and the emergence of new networks of information and trade. Technology, politics, and economics are intertwined. New political orthodoxy was coming of age.

In the early 1970s economists in the US began to play a primary role in shaping public policy. But everything changed. Rich economies were assailed by a toxic combination of low growth and high inflation—known as "stagflation." Milton Friedman believed that markets would work better if the government got out of the way. Friedman's acolytes advocated a new approach. By rolling back regulations and cutting taxes, governments could unleash the power of the market—and bring the return of high growth and manageable inflation. Friedman's famous doctrine held that the social responsibility of corporations and the business sector was to increase profits. With the election of Ronald Reagan in the US and Margaret Thatcher in Britain, these ideas found their way into government. Both administrations sparked a bonfire of deregulation, stripping away perceived hurdles to businesses' success. Free-market economics helped drive globalization, which helped kindle the Exponential Age.

Just as important was the emergence of a new political orthodoxy. From the late 1970s onwards, free-market capitalism would unleash the power of exponentiality. In 2010, 300 million smartphones were sold; by 2015, annual sales reached 1.5 billion. Between 2014 and 2015, the global average cost for solar photovoltaic energy dropped below that of coal. 2011 was the 1st time for decades that the world's largest company was not an oil company: Apple passed ExxonMobil. We are no longer just living in a period of exponential technologies—but at a time when these technologies and their effects are a defining force in our society.

Amazon's success is an annual research and development budget that reached a staggering $36 billion in 2019. It is not far off the UK government's annual budget for research and development. The entire US government's federal R&D budget for 2018 was only $134 billion. 19 years earlier, Amazon's research budget was $1.2 billion. Over the course of the next decade, the firm increased its annual R&D budget by 44%/year. In the process, Amazon created a chasm between the old world and the new.

Linear thinking, rooted in the assumption that change takes decades and not months, may have worked in the past —but not anymore. This divergence between the old and the new is one example of what I call the "exponential gap." Moore's Law means that every 10 years, the cost of the processing by a computer will decline by a factor of 100. Organizations that understood this deflation, and planned for it became well-positioned to take advantage of the Exponential Age. The bosses at Tesla understood that prices of electric vehicles might decline on an exponential curve and launched the electric vehicle revolution.

Most of the institutions that make up our society follow a linear trajectory. Stability is an important force within institutions. In fact, it's built into them. The gap between our institutions' capacity to change and our new technologies' accelerating speed is the defining consequence of our shift into the Exponential Age. Ever-more aspects of our lives will become mediated by private companies. What we once considered to be private will increasingly be bought and sold by an Exponential Age company. The most basic cause of the exponential gap is simple: we are bad at math. I've owned the Bee Gees' Saturday Night Fever on 5 different formats: vinyl record, cassette tape, CD, MP3 download, and now, streaming access. Exponential processes are counterintuitive. And we struggle to grasp them. Most processes we go through follow a linear scale.

A leisurely rhythm of life defined our existence for almost all of human history--even in the most industrialized nations, like the UK and US, it took until the 1920s for half of the population to live in cities. Over 2 decades I've observed executives in established industries regularly, perhaps even deliberately, look at the spread of a new product or service and dismiss it. Predicting the future is hard; predicting it against an exponential curve harder still. The human brain has about 100 billion neurons and 100 trillion connections. A machine that mimics the complexity of the brain could be built within a few decades. You make roughly 160 decisions for every mile you travel. When based on a near-limitless number of variables, the scale of the challenge for self-driven vehicles comes into sharper focus. And these problems of underestimation and overestimation are confounded by a 3rd difficulty—unforeseen consequences that don't feature in our predictions at all.

If the primary cause of the exponential gap is our failure to predict the cadence of exponential change, the secondary cause is our consequent failure to adapt to it. In the 19th century, breakthroughs in industrial machinery catapulted the British economy into a position of global dominance. But there was a hitch. There was a 50-year period where British GDP expanded rapidly but workers' wages remained the same. Those with capital to invest in new machinery did well initially, because it was technology that was driving the growth. It took decades for workers' wages to catch up. The 1st effect of industrialization was an—often unwelcome—change in working conditions. Charles Dickens chronicled how the 19th century was a time of exploitation, misery, and feculence. Britain had a modern economy, but a distinctly premodern political order.

Institutions are the lasting norms that define how we live, the more enduring features of social life. A business is an arrangement between employees, bosses, and owners-- a state between its citizens and the machinery of government. Unwritten rules can have higher levels of adherence than written ones. In 1975, a Kodak engineer called Sasson was awarded US Patent 4131919A for an "electronic still camera." At the time, Kodak sold 90% of the photographic film in the US and 85% of its cameras—they felt little need to pivot their business strategy. "When you're talking to a bunch of corporate guys about 18-20 years in the future. When none of those guys will still be in the company, they don't get too excited about it," Sasson later recalled. The company even recognized the power of the internet, buying Ofoto, a photo-sharing site in 2001. But institutional knowledge held them back from reaching anything nearly as popular as Instagram, the most successful photo business in the world. Kodak sold Ofoto as part of its bankruptcy process in 2012.

In the mid-1990s, Microsoft spotted the internet as a technological disrupter late. It ceded key parts of the internet business, such as the e-commerce, internet search, or messaging markets, to other companies. Faced with the launch of the iPhone in 2007, the firm flubbed again. Microsoft's own mobile ambitions were left in tatters. The company launched its 1st Windows software for cell phones in 2000 only to mothball the project 15 years later. The CEO who replaced Ballmer would successfully pivot the company to take advantage of yet another technology shift in the 2010s—the rise of cloud computing for businesses—to help Microsoft reclaim its position as one of the world's most valuable and innovative companies.

The path an institution starts on can have long-running effects on our behavior—we get "locked" into a particular course of action. There are a few key ways in which institutions adapt in practice. These include layering (when new norms get built on old ones), drift (where an institution keeps its policies in place, in spite of a changing context), and conversion (when an institution takes an old way of doing things and redeploys it in a different context). A good example of layering comes from the UK's National Health Service (NHS), which until 2020 was still regularly using pagers to exchange messages. The NHS started using them in the 1980s, before the age of cheap cell phones. The more they were used the more embedded they became in NHS systems. And the more embedded they were the more practices and norms were built on top of them—even long past the point when they had been surpassed. New institutions built on the back of pre-existing ones. Layering in action.

On occasion, institutions can lend themselves to very rapid change. Wars and revolutions help. The visceral shock of World War II and the need to find a solid base for international cooperation provided the impetus to establish many institutions, such as the United Nations and the General Agreement on Tariffs and Trade. As of the early 2020s, exponential technology has become systematically important. Every service we access, whether in the richest country or the poorest, is likely to be mediated through a smartphone. We are witnessing the emergence of a 2-tier society—between those who have harnessed the power of new technology, and those who haven't.

If you have ever worked at a very large company, you'll be familiar with how bureaucracy creeps in and slows everything down. In industry after industry, one could feel the gravitational pull of scale. It led to a phenomenon called diminishing marginal returns—that is, a decreasing return for every dollar a company invested. Companies would normally get to a certain share of a market and no bigger—40% was about as good as it got. If they tried to raise prices, a competitor could step in. In the odd instance where a single firm did have a big market share—50%, 60% or more—everyone acknowledged you had a problem. Such market dominance might even provoke the ire of the state. Yet when we turn to the corporate titans of the Exponential Age, we see a very different picture. Google's market share of search queries is almost 80% in the US, 85% in the UK, and nearly 95% in Brazil. In the smartphone market, Android is installed on 80% of phones globally, with Apple's iOS used on the vast majority of the others. In the world of cab riding--"ride sharing"—Uber controlled 70% of the US market in 2020. Walmart, had a little over 25% of the US's offline retail market in 2017. When it comes to the internet, Amazon's market share across online commerce looks set to grow well above its current level of around 40%. Exponential technologies seem to imbue companies with powers that allow them to defy the force of gravity that held back firms of earlier generations. Economists call this type of firm the *superstar company.* Superstar firms get bigger and bigger, dominating one market, then the next.

About 10% of the world's public companies create 80% of all company profits. The more digitized an industry, the more prone it seems to superstarification. The top 25% of IT firms were 4 times more productive than the bottom 25% in 2015. But that gap was only a factor of 1.5 in the shoe and cement industries. In the exponential economy, the winner takes all. Today's largest firms tend to superstardom. The rapidly declining costs of exponential technologies are part of the cause. Another is a positive feedback loop that turns market leaders into a kind of perpetual motion machine. Massive scale emerges organically. And while superstardom may be beneficial for shareholders in these firms, it is by no means clear that it is good for the economy, or for society. There is an exponential gap—a mismatch between the ways superstar firms operate, and the norms, conventions, and rules used to keep them in check. The exponential gap is taking over our companies, and in turn, our economies. In the new economic landscape, any small advantage can be turned into a bigger one and then, possibly, a lasting one.

When only one person has a fax machine it is effectively useless; when thousands have one, suddenly it comes in handy. Economists call this sort of additional advantage an "externality"—that is, an outcome external to the buyer and the seller, instead affecting a wider group who aren't involved directly in the transaction. Air pollution—is a negative externality. Positive externality: the "network externality." The network effect—in which the addition of every new member of the network increases the value of the network for everyone—is not new. It is why people have gathered in physical markets: This positive feedback loop makes the business better and stronger as it gets bigger.

Once Microsoft took pole position, its operating system became the dominant choice for developers. The network effect driving Microsoft's success allowed it to spread inexorably from one market area to the next—1st operating systems, then word processors, then spreadsheets. Wikipedia becomes the space where contributors want to write. Once a company has established itself as the market leader, it becomes extremely difficult to challenge it. And this effect is being driven by the consumers themselves. Today's digital giants can rely on their customers already accessing a communication network: the internet. The connections that support the network effect are already there. Rather than being suppliers of goods, firms can think of themselves as "platforms"—meaning they connect producers to consumers, without themselves doing much producing (or consuming).

The step-by-step process is known as the *linear value chain. The* organizational structure of such a company, from goods into manufacturing, packaging, distribution, marketing, and sales reflects its internal value chain--designed around a series of sequential steps. Compare that with a company like eBay. Rather than being rooted in a production line—a linear value chain—it is a *platform*. It is a space where sellers can meet buyers to sell their own goods, with eBay itself producing and selling nothing. Digital technology has led to the emergence of new, unprecedentedly huge platforms. These have the quality of the marketplace, bringing together different groups and waiting for magic to happen. But they have no real limitations of scale. This unleashed power of platforms is the 2nd key driver of the rise of superstar companies.

The growth potential of these companies is turbo-charged further by another factor: platforms are incredibly capital-efficient. The platforms facilitate an exchange without having to spend any (or much) money. The world's largest cab company, Uber, owns no cabs and employs no drivers. Airbnb hosts more overnight guests than any hotel chain yet owns no hotels. Alibaba is the world's largest online showroom for businesses yet holds no stock. They rely on 3rd parties using their platform to provide stock, warehouses, and logistics themselves. All this means that the platform business model is increasingly ubiquitous. Exponential Age platforms can creep into any geography and any industry.

The interaction of these network effects and platforms leads some organizations to rapidly become dominant. But there's a 3rd force that makes them even more unassailable—their basis in the "*intangible economy*." The software that runs Google's search engine, the data that represents the network of friends in Facebook, the designs and brand identity of Apple, the algorithms that recommend your evening's viewing on Netflix—this is where their true values lies. Economists call these non-physical assets "intangible." In 1975, 83 % of the market value of companies on the Standard and Poor 500 stock market index comprised tangible assets. By 2015 those proportions had reversed. Only 16% of the S&P 500's value was accounted for by tangible assets, and 84% by intangibles.

In 2019, the book value of the 5 biggest Exponential Age firms—Apple, Google, Microsoft, Amazon, and Tencent—ran to about $172 billion. This largely ignores its intangibles. Book value is a company's cash, what it is owed by customers, and its physical assets, minus its liabilities. The stock market valued those firms, at the time, at $3.5 trillion. In other words, traditional assets represented only 6% of what the market thought these companies were worth. Today, the value of a product tends to come from the early stages of its creation (its research and design) and in the later stages (the branding and service). What has caused this migration?

Complex products require know-how rather than stuff to put together. It is the know-how that goes into the manufacturing process—turning sand into a chip, and then connecting that chip to thousands of other components in just the right way—that makes it worth so much. Intangible knowledge is expensive to produce the 1st time and cheap to copy. In the intangible economy, companies can scale at an unprecedented pace to an unprecedented size. If the network effect ans platform are the foundations of the exponential company, then intangible assets are the bricks that make it up.

AI is the ultimate intangible asset, because it takes on the qualities of a perpetual motion machine—the algorithms give you more and more value without having to do much. Google was the 1st search engine that effectively captured data network effects. Google uses data about which links you click on (and which you don't) to improve the quality of its rankings. Every time a user clicks on a site and stays there, Google's AI learns that the link is useful; every time a user ignores a link, or clicks it then promptly hits "Back," Google learns it is more of a dud. And so every click feeds into the algorithm. Google is the ultimate network effects machine. Data network effects are like a perpetual motion machine for intangible assets. When a company is trading in intangibles, it need not worry about building new factories, or extending its supply chains. Growth takes care of itself. This is a world in which network effects are key--platforms, in which network effects are unusually powerful. It is further catalyzed by a wider economic shift towards intangible assets

By 2010 all large mature companies had stopped growing. But among superstar companies, this inherent tendency towards stagnation no longer seems to hold. The most valuable firms in the world—Apple, Google, Microsoft, Facebook, Tencent, Alibaba, and Amazon—are all Exponential Age companies. And despite their scale, the digital giants' revenues are still growing at a clip we'd associate with much smaller, younger firms. Ours is the 1st-ever age of increasing returns to scale. Netflix has followed a similar pattern. In 2010 Netflix had sales of $2.1 billion and 2,100 employees. Each one of them could account for slightly less than $1 million in revenue. A decade later, the firm had grown more than 10 times in size, with revenues approaching $25 billion. Its 9,400 employees accounted for nearly $2.7 million in revenue each. In 2012 Netflix's launched production. By 2019, it released more original shows and films than the whole TV industry's yearly output prior to 2016. Increasing returns to scale aren't just rewiring business, but also culture and wider society. Businesses based on network effects operate differently from traditional firms. Managing becomes redefined as a series of quests for the next technological winner—the "Next Big Thing." They are obsessed with growth--blitzscale growth over efficiency, even if it is expensive to do so. Founders identify markets where they are substantially better than any existing competition—so they can gobble up market share in a way that would have been unthinkable just a few decades ago.

First there is "horizontal expansion."--when firms move from one market to an adjacent market. Amazon, a retailer, has moved from selling books to peddling virtually every type of tchotchke. It has a logistics wing, the world's largest cloud computing business, and—like Apple—a media business. The 2nd form of superstar growth is vertical expansion. This is where a firm looks at the activities of part of their own supply chain and decides to bring them in-house. Google's advertising business, responsible for virtually all the firm's revenue and profits, is a vertically integrated system. Several different mechanisms make online advertising possible: targeting, auctioning the ad space, placing the ad, tracking the engagement. In 2010, Google acquired 40 companies—a diverse portfolio of firms that specialized in social gaming, photo editing, computer processors, touch typing, voice recognition, travel, and music streaming. All of these acquisitions allowed Google ever-greater control of its own supply chain. The big computer companies are making their own chips. Finally, in addition to expanding into pre-existing markets, these superstar companies have the budgets to invent new sectors of the economy from scratch. They invest heavily in research and development. Google's R&D spin-off, X, has funded experiments in manifold sectors—the life sciences, consumer internet access, self-driving cars, cyber security, machine learning. This confirms that the superstar company is not a fleeting trend but a wholly new economic paradigm.

In every area of the digital economy, the consumer experience seems to be getting cheaper and more efficient.

Modern monopolistic businesses might exploit smaller-scale producers. This phenomenon—of oligopolistic practices that hurt sellers rather than consumers—is common across Platforms. Start-up creation is becoming less and less concentrated in the US. In 1995, virtually all venture capital flowed to American startups, but by 2020 about half of all investment went to companies outside of the United States. Very large firms are increasingly adept at cementing their own position in that market—by buying nascent competitors when they are young. Research shows that breakthrough inventions are more likely to come from individual inventors or smaller teams. Much of the research conducted by companies tended to be very narrow compared to academic research and tended to reduce the number of pathways being explored.

Between 1997 to 2006, AI academics were 100 times more likely than life scientists to move from academia to industry. With the brain drain from universities to the private sector, research is at risk of becoming more and more narrow—increasingly focused on the commercial priorities of big companies. The bulk of the assets for Exponential Age firms reside in intangibles, and intangibles are prone to sliding across borders—and easier to slip past the taxman. In the years to 2020, the largest American tech firms paid a tax rate of around 16% of their profits, far below the then 35% corporate US tax rate. We need to develop a new way of thinking about monopoly. Once we have a new set of rules which deal with large companies in place, it will become somewhat easier to prevent the superstars wielding too much power. Today, *interoperability* between platforms is all too rare.

Insisting on interoperability, especially for firms that get to a certain size, is one way of tampering with the network effects that enable companies to get ever larger. The ability to freely access subscribers on any network, coupled with declining prices, drove up phone usage. Companies' fear of interoperability proved misplaced—they were stronger than ever, and customers' experience was vastly improved. We can limit the power of gargantuan Exponential Age firms by treating them less like ordinary companies and more like utilities—the essential services that we can't avoid, like water, or the electricity network, or sewage pipes. It is hard to participate in the local economy, let alone the global one, without a smartphone. "Universal service obligation": every resident of a country must be offered reasonable telephone services. Others must share their infrastructure with competitors in a fair way. All of these policies are about closing the exponential gap.

If you want to recognize a person from a photograph, AI does it better than an employee. If you want to translate quickly between 2 languages, AI will do it better than you. If you want to schedule shifts for 50 different workers, an optimization algorithm will thrash any person's timetabling attempt. And with every year, these algorithms get better and better at tasks we used to think of as quintessentially human.

Historically, our economies have become more automated. And historically, employment levels have tended to Increase because automation has the potential to create more work than it destroys. We are witnessing the emergence of an exponential gap between the working arrangements enabled by rapidly improving technologies and the outdated norms, regulations and expectations that govern working life. The use of sensors and analytics allows employers to implement automated management systems designed to boost efficiency and productivity—often at the expense of workers' wellbeing. And all the while, the share of value going to the workforce—rather than company owners—is declining.

AI breakthroughs were occurring in some of the most human-seeming of skills: perception, communication, planning, and manipulation. As much as 47% of the US workforce are in jobs at risk of redundancy to advanced computerized systems powered by machine learning. Employment in the American manufacturing sector peaked in absolute terms in mid-1979, when 19.5 million Americans held jobs in the sector. In 1980 it took 25 jobs to generate $1 million in manufacturing output in the US. By 2016, it would take just 5 to produce the same value of finished goods. The overall trend is towards more valuable companies with fewer employees.

On the one hand, automation seems to threaten a large fraction of the workforce. On the other, the better the technologies get, the more jobs there are. Moravec's paradox: It is comparatively easy to make computers exhibit adult level performance on intelligence tests or playing checkers, and difficult or impossible to give them the skills of a 1-year-old when it comes to perception and mobility. Many parts of workplace interaction are governed by undisclosed codes that emerge as you interact with your coworkers. There is a tacit dimension to our lives that is not codified, and perhaps never can be. This is perhaps even truer of supposedly "low-skill" jobs than of "high-skill" ones. Many jobs are based less on specific tasks and more on human interaction and emotional labor. If an environment is designed for a person, it is likely to be too complicated for machines now or any time in the near future. Production became automatable only because previously unstructured tasks were subdivided and simplified in the factory setting."

By the end of 2020, AI systems in software or in robots, were not making a dent in the employment statistics. The Amazon Go stores let shoppers wander in, pick up what they want and leave, with their purchases billed automatically to their Amazon account. Amazon is possibly one of most robotized large companies in the world with an astonishing 1 physical robot for every 4 workers. Amazon announced 4 waves of hiring, amounting to a staggering 308,000 new jobs globally in a year. Automation, growth, and increasing employee numbers go hand in hand. Where workers do lose their jobs due to automation, it's not because they themselves are replaced by some piece of software. It's often because the firms they work for fail. A recent survey of 587 manufacturing companies in France found that firms adopting robots became more profitable and productive. They also created jobs, increasing employment by 10.9%. A 10% increase in robot adoption by a firm was associated with a 2.5% decline in employment at its competitors. Machines were responsible for more than 650,000 job losses in the US between 1990 and 2007. Each individual robot displaced around 5.6 workers and reduced wages by up to half a percent.

A European study on industrial robots shows that each additional robot per 1000 workers increased overall employment by 1.3%. All in all, automation ends up creating jobs. As time has gone by, the estimates for net job loss from automation have been disappearing. In truth, the development of new technologies creates new need. The new sectors have needs that must be met by suitably skilled workers. For example, Aurora, a start-up building self-driving trucks, is creating entirely new categories of work, which look set to become increasingly common: from the people who manage fleets of vehicles, to the remote truck operators who help them deal with unexpected problems the trucks encounter while driving. In the end, across an economy, automation leads to more jobs, not less.

The historical record is unambiguous. Technologies have created more jobs than they have destroyed, but the short-term damage can be profound. If we're looking at the long-term fallout of exponential technologies, our concern should not be with the quantity of work for humans to do, but with the quality of options available. Uber has more than 20,000 employees, none of whom are drivers. Yet for every full-time employee, there are nearly 200 drivers.

Crowdsourcing: The internet connects people who need something done with thousands, perhaps 100s of thousands of those with the time and skill to do it. Programming or copywriting. TaskRabbit, now owned by furniture giant Ikea, will today dispatch someone to help you assemble your new bookcase. Talkspace will help you find a therapist. Wag! will find a walker for your dog. In time, the term "crowdsourcing" gave way to a new term: the "gig economy." The tasks—sifting through data, finessing product ideas—invariably relate to the development of intangible assets. And it is all facilitated by the internet, the smartphone.

In the UK, 2.8 million people are estimated to be platform workers—a shade under 10% of those employed. Gig work is a more imminent and transformative force than mass automation. Gig-working platforms make it easier to connect buyers and sellers—the databases and algorithms do the matching. Kobo360, a kind of Uber for freight, has helped Nigerian truckers get work in a famously inefficient market mired in corruption and bureaucracy.

The 2nd putative benefit of gig working is that it might qualitatively improve the nature of work. Lyft and Uber drivers show remarkable levels of satisfaction with the flexible work set-up: 71% of drivers want to remain independent contractors. In emerging economies, a gig-working platform may offer more security, more employment options, and greater freedoms than casual or day labor does. But pay is often poor compared to traditional work; working patterns can be precarious, offering few protections should a worker get sick. There is often no collective voice to represent their interests. This boils down to a huge imbalance in bargaining power between the platforms and their armies of labor and through low pay. The average Uber drive makes a profit of $3.37 per hour. In 2019 American workers for DoorDash, a food delivery service, made $1.45 an hour after expenses, or about 1/5 of the then national minimum federal wage. The deal is stability, in exchange for subordination.

There is an exponential gap—between new modes of employment enabled by exponential technologies and a set of labor laws designed in the 20th century. The 8-hour day, sick leave, pensions, collective bargaining—all were extended to those formally employed by a company. That workers are forced to rely on court decisions—rather than clear rules—reveals that the gap is far from closing. All of this leads to a growing inequality between gig workers and official employees. Only a small group retain the privileges that workers have fought to gain over the last 150 years.

Taylorism underpinned much of the productivity growth of 20th-century businesses. But it was also punitive, leading to constant surveillance of workers, draconian punishments for "underperforming" employees, and a tendency to treat workers like machines. The rule of Taylorism is that the unobserved worker is an inefficient worker. The classic 20th-century deal: you get a high-security, high-wage job in return for autonomy. Among technology companies, Taylorism was slowly abandoned, replaced by greater freedom for employees. Many firms today use facial recognition and mood detection systems, or are developing software that estimates how engaged and satisfied employees are.

As the technology gets more advanced, it gets more invasive. Some factories in China have garnered headlines for introducing brainwave-reading hats to track their workers' emotions and focus so they can adjust the length of break times to reduce fatigue. Unilever used AI to save 100,000 hours of interviewing time and roughly $1m in recruiting costs each year by delegating job interviews to video analysis software. A 2018 Gartner report found that half of 239 large corporations were monitoring the content of employee emails and social media accounts. The move to remote work during COVID-19 only accelerated this transition.

This system of management works like Taylorism on steroids—with all the dehumanizing downsides but without the commensurate high pay or job stability. Except, this time around, workers don't have the collective bargaining power they once did. Amazon automatically fires about 10% of its factory staff annually for not being able to move packages through the system quickly enough. Those who are well-educated and lucky can thrive. Those who aren't might find themselves trapped in an unprecedentedly punitive workplace. The future of work seems less defined by the absence of work and more by a growing chasm—between increasingly high-quality work for some, and increasingly low-quality, insecure work for others.

Between 1980 and 2014, labor's share of national income—the percentage of GDP paid out in wages, salaries and benefits—declined on average by 6.5%, as measured in 34 advanced economies. This manifested through stagnating wages and increases in inequality. Between the 1940s and the mid-1970s, economic productivity and workers' pay rose in tandem: in 1948–1973, there was a 97% increase in workers' hourly pay, against a 91% increase in economic productivity. By 2018, US economic productivity was 255% higher than 1948; but workers' pay was only 125% higher. The output of the US economy continued to rise—but the share workers received stagnated. Closely related to the shift to the exponential economy. 4 key causes stand out: Globalization; decline of unions; rise of the intangible economy which reduced the relative value-add of the average worker; and superstarification—as markets consolidated around ever-fewer superstar firms, there was less competition for labor and so workers had less leverage. More than 2/3 of the loss to workers results from the transition to intangibles.

The average software engineer at Uber was paid $147,603 a year in 2020. Senior engineers with 5 or more years of experience might make 3 times that. Your typical driver will make $19.73 per hour before expenses, or $30,390 a year if they drive 40 hours a week. Half of all employees at Facebook, from engineers to marketers, accountants to salespeople, make $240,000 a year or more. Facebook's content moderators are paid on average $28,000/year. Ordinary people who create the contacts, content, and conversation on Facebook are, of course, paid nothing. Middle-wage earners, who used to be the engine of Western economies, are evaporating.

We need 4 characteristics for a fairer work settlement. Workers need *dignity.* New technologies—even surveillance technologies—don't inherently lead to exploitation, provided workers are given *a say* in how these technologies are used. Workers should also be given more *insight into the data* that firms hold about them, and *clearer explanations* on how automated decisions are made. New technologies will continue to emerge and grow—cheap solar power, quantum computing, long-term battery storage, precision biology. How can we make constant reskilling possible? Digital technology can help us here. TikTok is rife with DIY videos—particularly in lifestyle areas like home improvement, cooking, and skincare. But people with specialist interests can also find communities. It points to nascent forms of digital learning, the more entrepreneurial and volatile the economy, the more essential such a safety net becomes. Many argue for universal basic income (UBI) to solve this problem.

Small-scale experiments in the US city of Stockton, CA and Finland's capital Helsinki have shown that people receiving UBI report increased wellbeing and lower levels of food distress. And when they lost their jobs, UBI recipients were nearly 1/3 more likely to get back into work within a year, relative to those who were on more traditional forms of assistance. UBI is already in place in Denmark—and is known as "flexicurity." Employers can hire, fire, and tweak employment terms at will. On the other hand, employees are guaranteed extensive protections and benefits from the state should they find themselves unemployed. For example, an unemployed Dane can make up to 80% of their previous salary. The Danish model gives firms the adaptability they need and the workers the security they need. Technology, globalization, the intangible economy—all shift power away from labor and towards capital. For every 10 new high-tech jobs, 7 new low-wage service jobs are created.

One reading of 19th- and early-20th-century history is as a long struggle by labor to organize. Unions have fallen out of fashion in the Anglosphere, following a 50-year assault by the political establishment. In 1981, the newly elected Ronald Reagan fired over 11,000 striking air-traffic controllers and replaced them with non-union members. It marked a turning point in the history of American trade unionism.

In the future manufacturing can happen near to the consumer. Thanks to the wonders of 3D printing, components can be produced locally; while the design might come from anywhere, the finished product can be crafted in a local workshop and handed to a customer who lives close by. The private sector had its own infrastructure of globalization. Annually at the World Economic Forum in Davos, political and business elites would get together to find common ground in this increasingly flat world. The power of globalization was transformative. In 1970, trade represented about 1/4 of global GDP. By 2019, it comprised nearly 60% of a much larger global GDP. Globalization coincided with an unprecedented increase in wealth around the world, as markets expanded and nations were able to reap the rewards of more open trade. Yet following the global financial crisis of 2007–2009, globalization started to lose its luster.

Exponential technologies both create the rationale for more borders and provide the tools to build them. They lead to a return to the local. These breakthrough technologies favor the near over the far. Exponential technologies also facilitate the local production of energy and food. And new technologies, and the businesses built on them, often need large numbers of people interacting with each other in close proximity—something only cities can offer. There is an irony here. The economic paradigm that brought about the Exponential Age, globalization, has fostered technologies that will lead to a return to the local. The world is not flat. It is very, very spiky.

There would be no need to exchange all those goods if you could source everything that you need locally. High-tech entrepreneurs have started to bring farming closer to where the food will be eaten. Urban vertical farms, popular in Japan and spreading elsewhere, are unusually efficient. A modern vertical farm may run to 12-13 stories high, each with a floor area of a few dozen square meters. This method increases the productivity of each square meter of "farmland": when built vertically, 40 square meters of growing area can concertina to nearly10 times that. Montreal's 160,000-square-foot Lufa Farms greenhouse, the world's largest, sits directly on top of a distribution warehouse. The market for high-intensity vertical farms is growing at more than 20%/year, on the march up our exponential curve.

Fossil fuels drive a large portion of world trade. But renewables have now put every nation on a path to energy independence. Between 1999 and 2019, British GDP increased 75%—yet the amount of electricity the economy uses declined 15%. We create twice as much wealth for every kilowatt-hour of electrical energy we use. While not every nation is rich in fossil fuels, solar energy is possible everywhere. The most solar-rich nation, Azerbaijan, only gets 4 times more sunlight per square mile of land than the most impoverished, Norway. The equivalent density between the haves and have-nots for oil is more than a million to one. The average electric car stores about 50 kilowatt-hours of electricity: enough to run the typical British or American home for 5 days. It will become commonplace for our electric cars to lend their stored electricity to our homes when it is dark. It is like alchemy—replacing a massive power station, smokestacks rising into the sky, with a web of cars, parked on driveways, keeping homes running as we sleep.

The wider trend is towards an economy based on ever less stuff. For many complex products, we are largely shipping around ideas. A $1,000 iPhone contains less than $400 in parts. The remaining 60% of its original sticker price are the intangibles—the design, the orchestration, and the brand. As new manufacturing methods mature, that ratio will only move in favor of intangibles. For the 1st time in decades, it makes economic sense to manufacture in places with high labor costs. 3D printing technologies are expensive because it is currently a low-volume game. But it will march down the curve of Wright's Law—getting rapidly cheaper, and in turn driving lower costs for complementary products--already improving 30%.year.

The diminishing dependence of rich countries on poor countries' commodities may fundamentally destabilize the economies of much of the developing world. 3D printing will put downward pressure on the value of world trade and may eliminate up to 40% of world imports by 2040. Since 2019, when the US achieved energy sufficiency through its investments in fracking—a new method of extracting natural gas from bedrock—the country has been more willing to see chaos in petrostates the world over. The institutions of a globalized world require nations to keep talking to each other, trading and cooperating. When the better-off world disengages from the economic wellbeing of the poor, it makes their path of economic development less clear. And it's a familiar pattern in the Exponential Age: high-tech, rich economies thrive; others get left behind.

From 2007 onwards, more than half of us have been city-dwellers. Cities have long been the engine of wealth creation, scientific discovery, trade, and culture. In the Exponential Age, this trend will not just continue but accelerate. As we progress through the Exponential Age, cities will become more important. Value in this intangible economy is created through highly complex products. Today, highly skilled knowledge workers are more in demand than ever. And these types of workers have never been evenly spread across a country. They cluster around universities, and the labs and resources they provide. And around those universities grow companies that employ the most-skilled individuals. Complex technologies—from biotech to artificial intelligence to chip design—need not just one but many specialists working together. And only cities can bring them together. Technology companies are willing to shell out for the eye-watering cost of doing business in San Francisco (or London, or Paris) because they are getting the benefit of an incredibly skilled labor pool. Today's intangible-powered cities are more specialized than ever. Delhi has Bollywood, Tel Aviv has cyber security, and Hsinchu, a mid-sized city in Taiwan, has become the global powerhouse for chip making. As strangers mix, new ideas pollinate. Cities are serendipity in action.

Cities differ from towns and suburbs in basic ways, and one of these is that cities are, by definition, full of strangers. Cities are characterized as one big positive feedback loop. As cities grow, the professional opportunities grow, the social life gets better, and the more attractive it becomes. They will continue to grow. By 2030, nearly 9% of the world will live in just 41 cities. In India, for example, urban dwellers enjoy more than double the average annual income of rural inhabitants.

As national governments have turned against migrants, cities in need of labor have taken a more open approach. And that makes them more welcoming to immigrants than their wider countries. We can begin to make out the contours of an Exponential Age society in which there are constant conflicts between cities and nations. A global data body could coordinate a consistent approach towards artificial intelligence, citizens' data and intellectual property. Keeping data flowing between borders would help prevent economies falling into siloes. *Digital minilateralism* means the cooperation of small groups of nations on questions of how to regulate the digital world. Minilateral organizations may be more agile and thus more able to make meaningful progress.

Just as the price of computing has collapsed since the 1970s, so the cost of building certain types of weapons is declining precipitously. Computer viruses and other malicious codes are driven by the same dynamics that give us better laptops and cheaper cell phones. The price of military drones has declined by a factor of 1000. None puts the attacker in the immediate line of fire. As digital devices have proliferated, so too have our vulnerabilities. When nations trade, they become economically interdependent. Conflict becomes an inconvenience—it gets in the way of business. The turn against globalization may well lead to greater conflict between nations. Conflicts within nations are becoming more commonplace.

Since the1990s the nature of war has become more fragmented. Conflicts are more likely to unfold within countries than between them. Growing urban-rural divides, the increasing weakness of intergovernmental bodies, and the declining cost of military technology have all drawn non-state actors into the fray. 96% of businesses in Britain suffered a damaging cyberattack in 2019. Data leaks are one of the most common consequences All the North Koreans need to wreak havoc is a computer and a talented hacker. This dynamic means many relatively poor nations can have a disproportionately impactful foreign policy. Hackers give the Iranian government an edge, and it is one they are keen to exploit. The Treaty of Westphalia of 1648 gave birth to the principle that the world was divided into sovereign nations with clear borders. The Geneva Conventions of 1929 and 1949 helped determine what was and was not legitimate targets for military conflict. None of these treaties are equipped to regulate a world in which thousands of actors seek to wreak havoc through digital subterfuge without any official acknowledgement of war. Most nations' cyber defenses remain feeble.

The steeply declining prices of weaponry catalyze conflict—drawing ever more actors into a digital or physical battlefield. The development of drones has driven an increase in "asymmetric" conflict—between powerful, well-established Actors like nation states, and upstart combatants with fewer resources. All of the current norms and regulations surrounding war are rooted in an assumption that governments are in control. When al-Qaeda operatives attacked New York and Washington in September 2001, it fell to the US military to respond. When Maersk and Mondelez were hit by cyberattacks almost 2 decades later, it was corporations that mounted the 1st defenses. Many in the West are "strategic snowflakes." Our daily life is enormously fragile. But there are some positive changes as well. Landmines have become increasingly rare since a treaty of 1997, as have cluster bombs since a treaty of 2008.

The data sphere grows by about 18 million gigabytes per minute. Genetic testing of the type that 23andMe and others undertake is not covered by HIPAA or similar laws. Voluntary guidelines have no enforcement mechanism and are all being profiled on the basis not just of our behavior, but also of our demography. And demographic profiling leads, inexorably, to prejudice. Our private information is sold back to us, then used to profile and manipulate us. In the Exponential Age, what gets measured gets managed. And in a data economy, we are the ones being measured. Homophily makes life easier but can lead to a kind of social breakdown. Polarization erodes the ability of a democracy to function. When our social bonds are formed solely through Exponential Age platforms, homophily is at risk of spiraling out of control. The technologies of the Exponential Age have made a common but formerly low-level feature of our social lives ubiquitous. Social networks are more homophilous and clustered than the rest of society. There is a commercial incentive to group similar people into progressively more precise, and discrete, segments. Recommendation algorithms are designed to get increasingly bored users to stay on a website. The best wayto do that, the algorithms have discovered, is to promote progressively more borderline and extreme material.

It seems as if you are never 'hard core' enough for YouTube's recommendation algorithm. YouTube may be one of the most powerful radicalizing instruments of the 21st century. Users consistently migrate from milder to more extreme content. Social networks were used in recruiting new members to the terrorist group ISIS. Facebook's own research corroborated these findings. 64% of people who joined extremist groups joined due to Facebook's recommendation tools. The algorithms exploit the human brain's attraction to divisiveness. Such shifts would lead to a fundamental erosion of the ideals that undergird a functioning society—the shared experiences, values and objectives that bind us together.

The data economies of the Exponential Age are radicalizing and dividing us—limiting our ability to be good citizens. They lessen our ability to uphold the democratic institutions that allow society to function. Broad principles underpin the relationship between citizens and the market. 1st, *transparency*. Algorithms must be easier to scrutinize. We also need external parties to be given oversight of the outcomes of that process. 2nd, *interoperability*. If we were uncomfortable with the way one company was using our data, we could switch to another—while still able to act in the digital social space. It would force competing platforms to behave better. Until about 2016, digital platforms were more open than today. Interoperability is kryptonite to the winner-take-all power of network effects. Networks all have the same messaging formats now anyway: textual messages, video messages and stories. Governments must act decisively. Interoperability unshackles our data from any one service and helps diminish the control the current and future tech giants have over us all. But it does little to address how we should use the data itself. We each deserve authority and oversight over our data. As network effects took hold, clear winners emerged-- LinkedIn for business users, Facebook for friends, Twitter for news addicts, Instagram for pictures. Openness played 2nd fiddle to competitiveness. Interoperability redresses the power imbalance between large platform companies and individuals. People must be secure against unreasonable surveillance. No one should be unfairly discriminated against on the basis of data. Individually, data—however well protected—isn't that interesting. It is in aggregate that it becomes useful.

We need to create a raft of new commons—which will prevent the creeping power of the private sector in every sphere of our lives. Intangible assets are prone to management by the commons. Unlike fish in an ocean or trees in a forest, digital resources do not get used up. In fact, the more certain types of information resources get used, the more of those resources there are. The goal of the UK Biobank is to enable novel scientific discovery with the consent of those who have contributed their data, a system built using a commons. The open-source software that powers the engines of web servers and other key internet services is one. Linux OS, the Apache HTTP Server, Mozilla Firefox, and the Brave browser. Wikipedia is visited by more than a billion of us every month, and edited through the collective goodwill of more than 120,000 volunteers--"comedy of the commons."

4 prescriptions—transparency, interoperability, rights, and commons—amount to a new way of thinking about the relationship between citizen and market. We're in a race not just to limit the new rule-makers' influence, but also to return power to somewhere it will be exercised openly —to put exponential citizens, acting in their collective interest, in control. Moderna, managed to produce the first vials of its vaccine on February 7th, 31 days after the sequence of the virus was initially released, America's National Institutes of Health, a mere 6 days to finalize the sequence of the vaccine, and a further 25 days to manufacture. The meningitis vaccine took 90 years to develop, polio 45 years, measles a decade. Scientists created an effective vaccine for mumps in 4 years. Moderna developed its vaccine with a "modified messenger RNA," or *mRNA*, a method that involves teaching our cells how to create proteins that resist a virus. Thanks to the power of machine learning, the computational tools used by Modern compressed some tasks that usually take years to just hours. Many of the services that were a lifeline in 2020 were less than a decade old—yet under lockdown, few could imagine a time before them. YouTube was founded in 2005; Netflix launched online streaming in 2007; Zoom launched in 2011; DoorDash in 2013. Fewer than 1 in 5 US homes had broadband in 2003.

We are entering an age of abundance--the 1st period in human history in which energy, food, computation, and many resources will be trivially cheap to produce. The cheaper something becomes, the more people can afford it, and so the more demand there is. Supply catalyzes demand. The risk is that reduced costs lead to gross increases in consumption. Without the right governance, they may still lead us down the road of overconsumption and environmental catastrophe. The effects of this destabilization are usually borne by those who can least afford them. Technologies have led to the creation of superstar companies. And these firms have capabilities that even governments need to rely on. Unaccountable influence goes to the individuals and places—high-tech knowledge-workers, cyber criminals, malevolent states—that 1st understood the power of exponential technology. Yet technology doesn't determine how it develops. We do. Acknowledge that technology's shape, direction, and impact is not preordained. Consider DDT, which was very helpful at killing mosquitos and slowing the spread of malaria, but also polluted food chains around the world. DDT was banned in the United States and United Kingdom. Yet for decades it was allowed in India where preventing malaria was a priority—and so ecological damage was deemed an acceptable downside.

Technology is not good, bad, or neutral. It brings change. While we can shape it, technology will nonetheless bring rapid, often unexpected dislocations. Chaotic, unpredictable developments can be for the good—it's our responsibility to direct them where we can and manage their surprises when we can't. In all of its guises technology functions as an instrument of governance. It molds all of the ethical, legal, and social systems on which we depend. We cannot prevent this molding happening, but we can direct it. We need new ways to empower working people. Through new forms of collective action which will allow workers to exert pressure on their employers. We also need new organizations to maintain international cooperation, to prevent much of the world being shut out of the benefits of exponential technology. We need to rethink the relationship between citizen and society, particularly surrounding the role of the market in our lives. We need a new set of tools if we are to thrive as we accelerate further into the Exponential Age. The 1st principle is *commonality*. As the world changes at an increasing pace, no state, business, or worker will be able to keep up alone. The 2nd principle is *resilience*. The world is developing faster than ever, and we need institutions that are sturdy enough to handle constant change. Our 3rd principle is *flexibility*. Our institutions need to be able to adapt quickly, as society around them changes. The industrial age brought new technologies: the internal combustion engine, the telephone, electricity. In response, humans built social institutions that adapted these technologies to their needs: secure jobs and collective bargaining for workers, national electricity boards, road safety manuals. The ideas of universal suffrage, permanent employee contracts, and global supply chains once seemed the realm of fiction too. Modern history is defined by 2 great forces: the extraordinary power of technological change; and humans' ingenuity in forging the world we want in response. Technology, it turns out, is something that we can control. Technology always has the potential to be a force for good.

[Wright's Law: For every doubling in units produced, costs fall by 15%--otherwise known as the "learning rate." It better describes what happened to silicon chip prices than Moore's Law. Free-market capitalism unleashed the power of exponentiality. Stability is an important force within institutions. In fact, it's built into them. Exponential processes are counterintuitive—most processes follow a linear scale. Executives in established industries regularly look at the spread of a new product or service and dismiss it. **Influence goes to the individuals that 1st understand the power of exponential technology.** In the end, across an economy, automation leads to more jobs, not less. Platforms are incredibly capital-efficient. In all of its guises technology functions as an instrument of governance. It molds all of the ethical, legal, and social systems on which we depend. We cannot prevent this from happening, but we can direct it.]