Data, New Technologies, and Global Imbalances

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Beyond the Obvious

By

Georges Kotrotsios

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To those who do their best to bring beauty to life,
and to those who bring beauty to my life:

Yoann, Myrto, Stefi.

TABLE OF CONTENTS

PREFACE

THE 3 AS

Αξιοπρέπεια, Αλληλεγγύη, Αρνηση: three Greek words, which translate to dignity, solidarity, and refusal. It was the summer of 2013 or 2014, in Chalkidiki, northern Greece. Vassilis Papakonstantinou, since the mid-seventies a living legend of Greek rock music, was giving a concert, to the applause of his young (and less young, including me) fans. Then, at the end of the concert, he explained the three *A*s, his three *A*s—which we need, according to him, if we are to make our society liveable. I am really grateful for having heard, from this great person, these simple, impactful words, these three *A*s. Myself, I would change the last A to another word: Αμφισβήτηση. This means "doubt". I believe that Αμφισβήτηση — constructive doubt, my third A—is vital to our efforts to build upon the past while, when necessary, circumventing concepts that block our path on our journey to the achievement of dignity and solidarity, all in the context of the disruptive, technology-driven changes society and the economy are currently undergoing. Whatever the last A is, it has to do with how to achieve the two first *A*s.

Beyond any specific analysis that this book attempts, beyond potential ways to balance imbalances, the first two *A*s, dignity and solidarity, are the beacons we must not lose sight of.

When imbalances between regions of the world, nations, individuals, and—I dare to use the term—"classes" of people (though I believe that "class" today has a very different meaning than that conveyed by its original Marxist definition) increase at a rapid pace, keeping dignity and solidarity in mind are keystones in the maintenance of a sustainably liveable society. The reasons for global (and local) imbalances go well beyond the impact of technology and science. But science and technology are playing an increasingly important role, as we are here to extensively discuss.

I wish to thank the people who provided valuable stimuli to the thoughts expressed in this book: First, my boss, Mario El-Khoury, for having created over the years, in the place where I spend my professional life, an environment conducive to open, stimulating discussion and analysis, as well as for his own rigorously analytical approach, which proved really valuable to my putting together the thoughts expressed in these pages. Olivier Parriaux, Professor Emeritus at Jean Monnet University, Saint Etienne, for long and valuable discussions on the political aspects of this analysis. My former colleague Aline Bassin—now an economics correspondent at the Swiss daily *Le Temps*—with whom I debated aspects of technologies and resources. Dave Brooks, who helped correct this text, provided invaluable help, always asking the difficult question regarding the meaning of my words, which itself pushed my thinking even further. And last but by no means least, the three people with whom I share my life: my two kids, Myrto et Yoann, and my wife, Stefi, who—through their love and patience—allow my brain to wander beyond the limits of the everyday.

CHAPTER 1

INTRODUCTION

Prior to the Industrial Revolution, wealth was—at least for the vast majority of people—directly linked to agriculture and the ownership of land: the more land a person, family, or society owned, the more domesticated animals this person, family, or society could support, and the more crops they could grow. Commerce and artisanal production were both based firmly upon raw materials, often the direct outputs of agricultural activity. War and related looting were, of course, another important source of wealth, as was the control of commercial roads. But again, in the majority of cases wars targeted the occupation of land in order to facilitate agriculture and access to commerce. This was a Malthusian (Malthus, 1798) society. Land ownership was a *casus belli*—a cause of, or sometimes a justification for, war.

What the Industrial Revolution changed was that machines were now able to produce wealth, since they could replace work, both agricultural and artisanal. In the industrial world, the accumulation of capital in the form of industrial machines became an additional source of wealth. Machines were (and still are) a multiplicative lever that enabled their owners to accumulate wealth at a faster pace, and more efficiently than an owner of land alone. As we transitioned from one world to the next—from the Malthusian to the industrial—wealth accumulation mechanisms changed radically.

The advent of the industrial world led to a decrease in the importance of agriculture, while increasing the importance of raw materials, either as inputs for the aforementioned machines (e.g., cotton, metals) or in the form of the energy required by those machines (coal, fossil fuels, nuclear fuel, and more recently renewable forms of energy, including hydraulic power, wind power, and photovoltaics). Land ownership remained a *casus belli*—as previously, in terms of agricultural resources (as was the case during World War II with the conflict between Germany and the USSR (Francopan, 2017)), but increasingly in terms of access to resources. The decrease in the importance of agriculture and the artisanal proved, in fact, to be extremely significant: agriculture currently constitutes less than 2 percent of the GDP of Western countries.

Today we are entering a new world: the data world. A new form of wealth is being added to all the previous forms, and that form is data. In this new world, data (and technologies that create and process data) is the factor that is changing wealth accumulation mechanisms and human societies' modes of competition in a completely new way, a way that we are only now starting to understand. The resulting impact is difficult to evaluate and goes far beyond the creation of certain large companies. It has to do with a redistribution of wealth between persons and between areas of the world. It also has to do with the extraction and accumulation of wealth. Land is becoming less important than it was in the Malthusian world or the industrial world, and is therefore less a reason for war. Wars are becoming increasingly commercial, and data is part of the weaponry, as well as part of the loot. Wealth extraction and accumulation are also changing. Increasingly, consumers are trading (or to be more precise, giving away) their wealth (i.e., their data) in return for services, including access to social media or search engines. To obtain all these data, adequate tools and resources are needed, and the interplay between three elements—resources, which have existed since the Malthusian world; manufacturing, initiated by the Industrial Revolution; and the digital technologies of our new, data world—is deepening, and shaping the world of today.

Of course, the challenges faced by human societies, both today and tomorrow, go well beyond the realms of science and technology. They have to do with ourselves, our relation to each other, and our relation to the environment, built or natural. These challenges are societal, economic, environmental, and political. They remain, however, strongly dependent on the accelerating pace of scientific inventions and technology-induced innovation, and the pace at which these challenges are changing is, thus, unprecedented.

To illustrate this in a more concrete way, I would like to take you on a journey back four centuries in time. In the late sixteenth century, the Dutch discovered how to use wind power to saw wood. The sawing of wood was important for the shipbuilding industry. Thanks to their invention, the Dutch were able to replace human power with wind power. The result? The acceleration of the shipbuilding process: a task that previously took six months now took only weeks. The seventeenth century was a century of Dutch global domination. Of course, technological innovation was not the only influential factor, but it was essential.

Wind power, associated with shipbuilding knowledge, created a competitive advantage of specialization, as theorized a century later by Adam Smith. The Dutch model, which we just examined, is a classical process of economic growth based upon technological innovation. Did it lead, however, to the same type of growth that we are experiencing today?

In the closing years of the last century, technology, IT, electronics, and robots replaced the human factor. This model was, in terms of its basic economic mechanism, very similar to the Dutch model of the seventeenth century: accelerating productivity.

So, what had changed between the end of the sixteenth century and the end of the twentieth? The answer to this question illustrates precisely the difference between the industrial world and the Malthusian world: productivity has increased, not only thanks to machines but also due to the accumulation of immaterial assets such as data (and algorithms); and wealth exists not only in the form of classical assets, which accountants—for example—are used to dealing with, but also in the form of data, which we cannot manage appropriately with our current accounting practices. The next question is, what is different today compared to the end of the twentieth century? The answer? The creation today of increasingly large amounts of data and the use of these data in the digitalization process. Such vast amounts of data can only be created because we have a convergence of factors. Today we are able to rapidly manufacture high-quality, affordable digital systems; we can access high-bandwidth communication networks that allow us to transmit data; we have at our disposal powerful computers equipped with high-performance algorithms that can store and process all these data; we have all accepted a common interaction protocol, the Internet.

The presence of these large amounts of data enables mechanisms that create innovation in a radically different manner. Further, the presence of data and these novel innovation mechanisms act in a different way on human societies and economies, transforming the way they function by disrupting processes. These transformations also change the way that industry produces, and as a consequence the way that technology develops.

Personalized health, the smart city, and the autonomous car are often-quoted examples of the evolving role of technology, industry, and the economy. The impact of this evolution can, however, appear in unexpected places in our societies. Gender differentiation is just one example. According to Lausanne's IMD Business School, in India men buy three times more than women over the Internet. We are not, here, judging this fact as either good or bad, simply presenting it as an indicator of differential gender behavior. Effects of gender-differential behavior certainly exist in other parts of the globe and in other domains, due—in particular—either to limited access to IT infrastructure or to gender-related discrepancies with regard to education.

A topic close to that of gender-differential behavior is birth control and the emancipation of women. These are, at first glance, far removed from technology. Throughout history, the practice of birth control has been more or less empirical and often quite random. Today, a sophisticated wristband—a kind of smartwatch—offers a precise indication of where a woman is in her fertility cycle. Is this good or bad? Can this technology be used widely, all over the world? These questions are open to debate. What is not debatable, however, is that the technology is here and has been commercialized, and that it has the potential to contribute to our efforts to meet societal challenges—even those as difficult to grapple with, a priori, as gender discrepancies or birth control—doubtless in both high- and low-income countries.

Leaving the domain of societal challenges behind and looking at environmental challenges, we see that issues such as arable land (which has a direct impact on food availability and quality) and water scarcity and control are becoming critical. Today, one third of arable land has been degraded by overexploitation: only precision agriculture can help humanity provide enough food, as we stand on the cusp of a world in which we will be asked to sustain nine billion individuals. Satellites with smart (hyperspectral) cameras, associated with smart terrestrial devices, can drive such precision agriculture. Robots with smart vision are being used more and more widely to optimize plant care and harvest agricultural crops. What does this mean? It means a change in agriculture as a process, and in value chains and the very jobs of those people who create the element that answers our most basic need—food.

We can also observe disruptive changes happening in an entirely different domain, that of the value chain of energy production and distribution: the logistics of energy generation by centralized nuclear and thermal plants are changing rapidly, giving way to a mix of centralized and decentralized energy production and usage systems that in turn require complex digital systems that allow real-time control and optimization.

In yet another domain, half of the world's freshwater flows across the borders of at least two countries, making the potential for disputes very real.

For two-thirds of these cases[1] there is no cross-border management system. Obviously, only mobile, sturdy, easy to deploy and use electronic devices can enforce fair monitoring. And it is not only the economy that is concerned here. Water is expected to be another *casus belli* in the decades to come. Proper quantitative monitoring can form a common basis of understanding, and a starting point for discussion. So, the challenge of water resource monitoring is not only environmental, but also political.

Societal and political issues closely related to the evolution of technologies are evident in our daily lives. According to the World Bank, average per capita wealth in OECD countries is more than 50 times higher than that in low-income, non-OECD countries.[2] Worldwide,[3] the "top" one percent (in revenue terms) of the population earns two times more than the "bottom" 50 percent. In Europe, the "top" 20 percent (in terms of assets) of the population earns five times more than the "bottom" 20 percent.[4] This discrepancy is continuously increasing. Is this only due to technology and to the growing role of data? Certainly not, but the complex interplay of the delocalization of the manufacturing industry and the increasing power of capital, particularly when that capital is interconnected with digital assets, is nevertheless an important factor, and one we will discuss below. And this discrepancy is also, at least partially, the cause of political and social unrest, including large migratory movements from poorer to richer areas of the world, or unrest within the same geographical area, the latter variety having a very recent example in the "yellow vests" (*gilets jaunes)* movement in France.

In the chapters that follow, we will try to analyze the mechanisms behind the role of technologies in these changes, along with these mechanisms' potential impact.

In "Technological Trends, Industry Trends, Impact on Society, and the Evolution of the Economy", the mechanism of accelerated, mutual interaction between technology trends, industry trends, and societal as well as economic

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[1] IMD International Institute for Management Development. "Access to water", IMD Global Signals, 2020 Edition. For more information on IMD Global Signals: https://www.imd.org/research-knowledge/global-signals/environmental/.

[2] https://openknowledge.worldbank.org/bitstream/handle/10986/29001/97814648 10466.pdf, page 45.

[3] wir2018.wid.world/files/download/wir2018-full-report-english.pdf, page 13.

[4] IMD International Institute of Management Development. "Rising inequality", IMD Global Signals, 2019 Edition. For more information on IMD Global Signals: https://www.imd.org/research-knowledge/global-signals/environmental/.

impact will be addressed, and the various interconnections and mutual interplays discussed. It transpires that all these interactions are growing in intensity: Everything in our economic and social lives (and also our political lives) depends on technological evolution and interactions. On top of this, these interactions are not only growing in intensity, they are also becoming more complex and evolving more rapidly. The main message is that private and public stakeholders need to take these interactions—these increasingly important factors—into account when it comes to public and private policy making. Understanding them is a first step.

In the following chapter, “Data and Resources”, we address the question of the often invisible role of resources such as energy, place, and bandwidth in our world. And if there is one resource that we cannot omit from our discussion, it is the human resource, which is the subject of the chapter “The Human Factor in the Digital Age: The Manufacturing Environment”. Here we will avoid addressing topics often covered by works appearing in the bibliography (such as, for instance, those covered in Rifkin’s *The End of Work* (Rifkin, 1995)) concentrating instead on changes to working environments.

The chapter that follows, “Comparative Advantage and Geographical Economic Clusters”, addresses the impact of technologies, in particular digital technologies, on the formation and the competitiveness of ecosystems, and on the risk of creating vast disequilibria that can only be addressed when adequate attention is paid to the processes of policy making and policy implementation. The importance of increased interaction—and on fairer terms—between the public domain and the private domain is also highlighted.

The sixth chapter looks at “Data, a New Form of Capital” and at how data capital can accelerate the creation of imbalances. Perhaps one of the chapter’s most important messages is that we no longer live in a world where capital cooperates with and competes with labor: today we have a triangle between capital, labor, and data capital. And data capital disrupts the traditional coexistence of capital and labor, creating a completely new economic and social landscape.

In the final chapter, “The Path Forward”, we present a number of disruptive proposals. These include the taxation of data, creating a (legal and regulatory) global governance mechanism for digitalization, and modifying the dominant culture of national state governance to incorporate a new, more entrepreneurial spirit.

The common theme of these different analyses is that technology is impacting resources (human, material, and immaterial) at a faster and faster pace, leading to the creation of disequilibria, whether these be geographically concentrated or geographically spread. If we fail to pay sufficient attention to these disequilibria and to the question of resources, our societies may disintegrate.

CHAPTER 2

TECHNOLOGICAL TRENDS, INDUSTRY TRENDS, IMPACT ON SOCIETY, AND THE EVOLUTION OF THE ECONOMY

Technology and society: Their changing relationship

Major technology trends, industry trends, and societal and economic evolution today form a complex puzzle. An understanding of the evolution of each of these elements and its impact on how this puzzle evolves can be useful with regard to the puzzle's overall optimization. When seeking to obtain such an understanding, an important tool is an analysis of the mutual interaction of these elements.

Given the ever-increasing importance of technology in the shaping of the societal and economic landscape, such an analysis can make a valuable contribution to the elaboration of measures that can mitigate potential societal or economic imbalances, maintain overall sustainability, and promote opportunities for better living.

To advance toward such an analysis is useful as it enables us to try to create a conceptual basis for the aforementioned mutual interaction, even if that conceptual basis cannot be either exhaustive or generally accepted.

We can visualize this proposed conceptual basis as existing on **three levels** that are parallel to one another: the technology trend level, the industry trend level, and the level of societal change. These levels interact with one another via a form of chain—a kind of imaginary arrow that traverses them. This arrow is bidirectional: as much as new technologies enable new industrial trends and impact society, societal changes require industry to follow, which in turn means new, adequate technologies.

At a high level we can state that all of today's major technological developments relate to one or more of three major **technological trends;**

namely, new manufacturing techniques,[5] digital technologies, and technologies related to resource generation, management, and access.

Technology trends are at the origin of the creation of **industrial trends**,[6] which can themselves be categorized into three groups: new manufacturing paradigms, digitalization, and the complexification of products and value chains.

In turn, industry trends impact societal evolution and create new economic effects. And both society and the economy are closely linked to politics and the environment. For brevity in the present analysis, when using the terms *society* and *the economy* we understand them to incorporate, if only as a backdrop, politics and the environment—politics as a regulator and the environment as a constraint and boundary condition. These three levels are schematically illustrated in Figure 2-1.

There exists a continuous interaction and **convergence** between technological trends. This convergence happens in multiple ways, as we will detail below. It accelerates and strengthens the chain of interaction between technology, industry, society, and the economy. A new key factor that has emerged over recent years is data. Its presence is the result of the intense digitalization of our economy and society. Data is also the oil that lubricates all these interactions, resulting in them both accelerating and strengthening. This acceleration and strengthening of interactions, in turn, allows the creation of even more data, in an upwardly spiraling mode.

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[5] For the sake of simplicity, biological processes that create new types of medication or even newly emerging artificial (human) organ technologies can be categorized as new manufacturing techniques

[6] Here, the words *industry* and *industrial* are understood to comprise all value creating economic activities, including those taking place outside of the secondary sector (i.e., manufacturing). Thus, service provision, for example, is included.

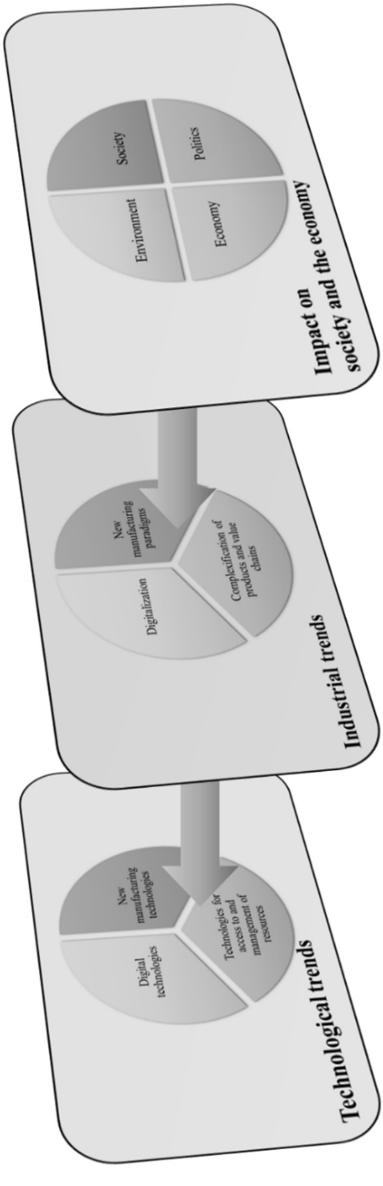

Figure 2-1. The accelerating evolution of technology in the form of its three key trends is having an increasingly strong effect on the way industry (including service provision) operates, which in turn creates rapidly evolving changes in how the key elements of our lives—society, the economy, politics, and the environment—function. We can observe that this effect is becoming stronger as time passes

Our analysis below is structured to follow the aforementioned logic: It starts with an analysis of technology trends, followed by a description of convergence mechanisms. Then, industrial trends are illustrated as are impacts on society and the economy. The mechanisms that link these three levels are discussed in depth. The focus then moves to the role of data in interactions, before the impact of these mechanisms on the sustainability of societal and economic change and the potential types of measures that society and the political milieu could adopt to support economic, societal, and ecological sustainability conclude this analysis.

Technological trends

The first step of our analysis is to try to understand the trends behind the big evolutionary changes in technology that are today commonly accepted as mainstream and involve technologies that are widely expected to mature further. These are diverse, and include the dominance of artificial intelligence, 3D manufacturing, 5G and 6G communication technologies, alternative energy, robotics, biotechnologies, artificial organs, augmented and mixed reality, the Internet of Things (IoT), quantum computing, augmented reality and related usages such as personalized health (which includes printed organs and vital sign monitoring), smart cities, and autonomous vehicles. Our first target, then, is to identify these "big rivers"—the **technology trends** that are the common denominators of all the aforementioned topics and that, today already, inundate our lives.

These underlying "rivers"—these technological trends that seem to carry with them everything in their path—can be gathered together into one or more of three big lines: digital technologies, new manufacturing technologies, and technologies that allow the generation of, access to, and optimization of resources.

Digital technologies

The term digital technologies includes all Internet and networking technologies but also extends further, including all technologies that allow the extraction of data and their transmission in digital form across communication networks. The information that we want to extract, copy, transmit, and process is in the vast majority of cases analogue at the macroscopic level, varying continuously (e.g., temperature, weight, light intensity, and color measurement). Every single device that is used to measure analogue information and transform it into digital form and then process it, store it, display it, and communicate it—still in digital form—is part of what we call digital technology. Today, such devices are everywhere. For example, 40 percent of the value of the average automobile is in the form of digital technologies, including sensors, geographical positioning systems, electronic driving controllers, and many other elements. Airplanes fly controlled by digital devices and systems. Factories are controlled by digital devices and systems. Household appliances such as refrigerators, ovens, and autonomous vacuum cleaners are controlled by digital devices and systems. And, of course, these are only a few examples. These individual devices, operating at the "edge" of electronic networks are the "things" of the Internet of Things (IoT)—the dimension of the Internet that is going to operate without human intervention. The IoT is only the natural extension of the Internet, an extension that humans will, of course, continue to feed with valuable digital information in the form of text and numbers, photos and videos.

Whatever we refer to today as artificial intelligence is also an example of digital technologies. Artificial intelligence comprises the very advanced algorithms that can replace basic human operations. It is expected that such algorithms will, in the future, be able to manage more and more complex functions.

Robots are "simply" complex mechanisms that can, today, carry out actions commanded by simple algorithms. Soon such algorithms will become more and more complex. But at some point more and more complex algorithms become artificial intelligence, which in turn becomes more and more evolved. Artificial intelligence, as it evolves, will be increasingly able to make decisions currently made by people or organizations, or at least give very precise information to people and organizations, allowing them to make these decisions while reducing uncertainty to the minimum.

Other technologies that can be categorized as digital include the upcoming applications of quantum communications and quantum computing, based—as their name suggests—on the quantum behavior of particles. Based on these "weird" phenomena, extremely powerful computers and communication systems are expected to become reality. Such computers will be able not only to perform calculations at previously unimaginable speeds, but also to run new families of algorithms that we are yet to conceive of.

New manufacturing technologies

Manufacturing technologies allow the realization of tangible "objects". These can be in the realm of what has been manufactured for many years, but with better quality and more features (automobiles, telephones, or watches), but they can also be new objects with as yet unseen functionalities and performance, such as smart objects (e.g., smart sensors or actuators), processors, robots, bio-medication, artificial organs, flat displays, or more efficient solar cells. Robotics and sensor and communication techniques—in other words, digital technologies—allow the very existence of such devices in forms that are reliable, and available at a commercially acceptable price and in a reasonably small form.

In turn, these novel objects allow manufacturing techniques to become faster, more reliable, interconnected (to improve logistics), efficient (to optimize cost and yield), and easily reconfigurable (to create customizable, versatile projects). Without digital technologies new manufacturing techniques could not be employed. From the opposing standpoint, the digital world cannot exist without real "things" that we can use. In today's world, the one cannot do without the other.

For reasons similar to those for which digital technologies should not be mixed up with the digitalization of the economy and society, we need to be extremely careful to avoid mixing up manufacturing technologies with the changing manufacturing paradigm, which we shall encounter below. The latter is an industrial trend, while manufacturing technologies are technology trends.

To illustrate the continuous evolution of manufacturing technologies, let's focus on a novel example: additive manufacturing. The concept is simple; the results can be remarkable. Additive manufacturing is the natural continuation of "classic" manufacturing. Additive manufacturing is the process of adding material to create monolithic and often complex forms. This can "simply" happen by heating and melting powders in a specific point in space, using a precisely positioned laser beam.

Despite the simplicity of the method, or perhaps because of it, the consequences of employing additive manufacturing can be significant. Additive manufacturing systems can be cheap because the necessary equipment is quite simple, and often inexpensive when compared to the complex machinery required for mass produced, "classically" manufactured goods. What does this mean? It means that individuals can buy one of these additive manufacturing systems. This means that each individual will—although, of course, we are stretching this logic to the extreme—be able produce his or her own goods, such as footwear and clothes, at home and at will. This ability may have a deep impact on manufacturing. The structure of the manufacturing industry itself might be modified. In some cases, instead of buying goods the consumer will be buying designs for goods, which she or he will be able to modify at will. Of course, it is currently inconceivable that mass-produced goods will cease to inundate markets, but additively manufactured goods will coexist with them.

Clothes and footwear are only two examples. Food is another example of a potential 3D-manufactured good, in this case biological and organic in structure. And if one can produce biological structures, why not produce organs—hearts and livers, fingers and skin? And this is precisely where we are heading. Additive manufacturing methods alone are not enough, but such methods will most probably play a key role in the building of biological structures such as human organs, which will change medicine disruptively. The implications surpass our imagination.

Since new livers, kidneys, or lungs can be produced, why not new *types* of livers, kidneys, or lungs—types that are improved and have other functions? Why not even combine a liver with a kidney, resulting in a new organ that performs the functions of the kidney and the liver simultaneously? And, of course, why not combine the biological with the inorganic in the same organ to increase functionality?

We have not, here, addressed the question of the increasing potential of biotechnology in terms of medication or sensing, only that of disruptive manufacturing. And here resides much of the subjectivity of paradigm choice. Is the manufacturing of organs (or augmented organs) more impactful than biotechnology as pharmacy? Perhaps not. What is more disruptive is the change of the paradigm of our society and our economy. And the choice of that paradigm is, therefore, pertinent. Medication is the evolutionary outcome of what human beings since the time of Hippocrates have been trying to do: have substances (natural or man-made) influence processes, which can be regular processes (so, for instance, aging) or processes that appear unexpectedly (illnesses). The manufacturing of organs is radically different conceptually: it has never happened before. Of course, both regular and known processes will be, potentially, replaceable by the manufacturing of organs. It is not unconceivable that more biological functions will be designed. Such new functions (activated by new types of organs) may include some that can today barely be even imagined. For example, today animal species such as whales and bats have the biological function of localization. Would it be feasible to invent (and manufacture) and implant new human organs that can perform such a function? Or fly-type eyes? Or scent organs that have the sensitivity of those of dogs, or even greater? Or biological organs that produce, directly, digital signals?

Technologies for accessing and managing resources

To begin with let's look at energy. The generation and management of energy, in particular renewable energy, are typically heavily dependent on cutting-edge technologies. The question of energy concerns not only the obvious energy consumers such as transportation, heating, and industry. Even "hidden" heavy users such as electronics can rapidly generate stumbling blocks. Today, the portion of global greenhouse effect emissions caused by digital technologies is approximately 4 percent.[7] In 2030 it may be between 6 percent and 14 percent.[8]

Technologies employed in energy generation and management are essential for both the success and the large-scale deployment of digital and new manufacturing technologies. Who would use a smartwatch that needs recharging every two hours?

The wise use of digital and manufacturing technologies can be a defining factor for the sustainability of our societies. Such careful use of digital technologies could preclude greenhouse effect emissions by a projected 9 percent overall by 2030.[9] Proper use of manufacturing technologies, meanwhile, can reduce the quantity of material resources used in manufacturing processes. Traditional manufacturing removes and subsequently discards, and thus wastes, material during the manufacturing process; additive manufacturing does not.

Energy is hardly the only resource that might be lacking in the decades to come. Other elements or resources that, for the time being at least, we assume will continue to be available in sufficient quantities—including bandwidth, storage space, and computing resources—might be available

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[7] https://theshiftproject.org/wp-content/uploads/2019/03/Executive-Summary_Lean-ICT-Report_EN_lowdef.pdf.
[8] http://www.electronicsilentspring.com/wp-content/uploads/2015/02/ICT-Global-Emissions-Footprint-Online-version.pdf.
[9] https://gesi.org/storage/files/__DIGITAL%20WITH%20PURPOSE_Summary_A4-WEB.pdf.

only at a premium. Today, the number of IoT (Internet of Things) devices are counted in the tens of billions,[10] and their number is expected to increase following a double-digit growth curve. Each one of them is measuring or monitoring and regularly sending information. This tsunami of data will be added to the already existing data streams and information communication channels used by people over the "regular" Internet to transfer photos, video, or text. Some ballpark figures are often quoted and give an idea of the expected orders of magnitude:[11] in 2020, every person on Earth is going to produce—on average—1.7 MB of data per second; over the years that follow, the pace of data creation may well increase at a double-digit rate of growth. Even if these volumes of data can be accommodated in 2020, this situation will not—in terms of storage, processing, and communication—be able to continue forever unless completely disruptive technologies such as quantum computing mature on time. Today, real-world[12] quantum computers are not yet a reality, and the eventual realization of real-world commercial devices is not even a certainty.[13]

Other considerations include the "footprint" of both IoT devices and the computers that will store this growing volume of information. The computing power necessary to process these mountains of data and, of course, the energy required to run these computers as well as to cool them constitute further challenges.

Resources are the basis of, as well as one of the key constraints on, what we need both for manufacturing and for digitalization. Resource access and management is one of the three pillars of sustainability (the other two being economic sustainability and social sustainability, which—as they are not technological trends—we will address at the end of this analysis). Sustainability is key: without sustainability, everything—from ourselves to the environment, society, and the economy—becomes unstable and either explodes or implodes.

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[10] https://www.statista.com/statistics/471264/iot-number-of-connected-devices-worldwide/.

[11] https://www.socialmediatoday.com/news/how-much-data-is-generated-every-minute-infographic-1/525692/ ;
https://www.ibm.com/downloads/cas/XKBEABLN.

[12] https://www.barrons.com/articles/google-ibm-primed-for-a-quantum-computing-leap-says-morgan-stanley-1503602607.

[13] https://spectrum.ieee.org/computing/hardware/the-case-against-quantum-computing.

So far, we have not addressed other essential resources such as water, food, and conventional fuel (oil and gas). Today, technologies support the extraction, exploitation, production, transportation, management, and distribution of all these resources. Their sustainability is as (if not more) important as that of the other resources discussed above. As they are only indirectly related to specific technologies, however, we can situate them much more comfortably in the fields of the economy and society, which we will discuss below.

Convergence

The three technological trends (digital technologies, new manufacturing technologies, and technologies for accessing and managing resources), and indeed all the technologies of today, coexist and interact mutually. This coexistence is the first step toward convergence, which we will go on to analyze. That convergence is a mechanism that creates an acceleration and a reinforcement of the impact of each one of the technological trends or industrial trends that we are here to address. Convergence happens in different dimensions.

Convergence between disciplines

Convergence occurs between technologies. A well-known case—and example—of convergence is often referred to as "NBIC", which stands for nano-, bio-, information-, and cognition technology convergence. This convergence can be seen in devices and systems that englobe technologies coming from completely different disciplines.[14]

In manufacturing terms, devices that necessitate technological convergence (such as that seen in NBIC) bring about an extremely strong diversification of equipment, infrastructure, and human-resource skills. Since multiple,

[14] One example that illustrates this type of convergence is security that is materialized by the use of micro and nanodevices. Nanodevices are expected to play a future role in protecting people and critical infrastructure from human threats. Efforts to contain such security threats (e.g., chemical, biological, or explosive) will benefit from the merging of both nanoscience disciplines (hard and soft matter) with biology. For instance, the use of specific antibodies encapsulated in nanodevices opens new routes to the multiplex detection of chemical, biological, or explosive agents. Appropriate nanoscale encapsulation allows fast and easy deployment over large volumes while maintaining sensitivity.

very different technologies are needed, the corresponding equipment, infrastructure, and personnel type are both specialized and very different from one technology to another. Equipment and infrastructure tend to be very expensive; people need to have dedicated, high-level skills. Few organizations throughout the world have the financial means to sustain the variety of equipment, infrastructure, and human resources required to cover, for instance, all of the NBIC technologies, with regard either to production or to R&D. Such convergence thus calls for **more complex value chains** that can fulfil all the requirements for products and services that are based on converging disciplines.

Coexistence of research, design, and engineering

Convergence and concurrent engineering can happen between the different phases of design (including material selection and engineering), device manufacturing, testing and feedback/optimization of design and manufacturing, integration of working systems, and functional testing. A reason for convergence between operations such as design, manufacturing, assembly, and testing might be the need for a shorter and shorter time to market at continuously lower costs. Closer and faster interaction all across the innovation value chain will, due to this type of convergence, require **faster, more digitalized processes**.

Coexistence of the real and the virtual

The third type of convergence, and perhaps the most iconic of our era, is that between the real and the virtual worlds. The Internet of Things is the most illustrative example. The Internet itself is the exemplification of the digital, the virtual world. The "Things" (of the Internet of Things) are the exemplification of the real world of manufactured devices. Without each of the two pillars "Internet" and "Things"—digital and virtual on the one side, real and manufactured on the other—the Internet of Things cannot exist. The IoT is increasingly present in our lives, in every respect, from health to entertainment, to transportation, energy, and far beyond.

Today we can have affordable and miniaturized IoT devices because:

- The microelectronics industry is enabling a dramatic decrease in power consumption requirements for the operation and miniaturization of effective devices.
- The energy industry is enabling the scavenging of energy from the environment, which makes possible the optimization of the energy

consumption of novel microelectronic devices, thus paving the way to a steep increase in their deployment.
- Communication technology is making advanced networking techniques—including 5G, but also numerous alternatives such as Lora, Wi-Fi, Bluetooth, and many others—a reality.

Thanks to these capabilities, and specifically their convergence and coexistence, the IoT can exist today, with—at its edges—devices that are quasi-invisible, are produced at very low cost despite the intense customization involved, and are rapidly invading our working and living environments.

Industrial trends

The three technological trends lead to corresponding industrial trends. In turn, industrial trends create a need for these technological trends. Three big industrial trends seem to stand out. The term *industrial* is used here to represent economic activity, and for the sake of simplicity in this text integrates both industrial production and service provision activities.

These three big industrial trends are:

(i) **Continuous change to and adaptation of the manufacturing paradigm**.
(ii) The **digitalization** of a continuously enlarging spectrum of activities.
(iii) The increasing **complexification** of products, processes, services, and related value chains.

A different classification might exist. What is important here, however, is that the very act of seeking such a classification allows us to facilitate the setting up of a conceptual framework and, further, to analyze the relations between the technology trends discussed above and industrial trends, and the differences between technology trends and industrial trends.

To illustrate the meaning of each one of these trends we can cite some examples. For instance, the **digitalization** of health means using digital technologies to make better diagnoses. **Digitalization** in industry means the use of digital technologies to make production more efficient and/or more secure. The digitalization of energy means the use of digital technologies to optimize the production of and commerce in electricity, and so on for all aspects of our social and economic lives.