Riding a new wave of innovations
A long-term view at the current process of creative destruction

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Every step and every movement of the multitude, even in what are termed enlightened ages, are made with equal blindness to the future.
(Adam Ferguson, 1782)

Whoever claims to be able to foretell the future is a liar, even if the actual course of events happens to prove him right.
(Arabic saying)

1. Introduction

The digitalisation of the economy and society and the expected effects it has on employment, the distribution of income and wealth, economic growth, personal freedom and wellbeing, national sovereignty and security, and so on, play an important role in the contemporary political and academic debate. Elements of the current wave of innovations are the theme of this essay. More precisely, we discuss the characteristics as well as risks and challenges of the digitalisation of the economy against the background of previous waves of technological change and embed our argument into the history of economic analysis and economic history. In particular, we aim at raising awareness of the potential drawbacks that accompany the current wave of innovations.

A bewildering number of names have been invented to describe the current wave of technological change: Brynjolfsson and McAfee (2014) see the dawning of a Second Machine Age based on advances in technologies such as robotics and artificial intelligence (AI); Jeremy Rifkin claims the arrival of a Third Industrial Revolution (2011), characterised by the merging of new information and communication technologies (ICT) and renewable energy; Klaus Schwab (2016) foresees the emergence of a Fourth Industrial Revolution through the fusion of novel and disruptive technologies from the mechanical, the digital and the biological sphere, a term which many use synonymously with Industry 4.0; whereas Carlota Perez (2013), much like Rifkin, interprets the ongoing transformations in the energy sector backed up by ICT as the continuation of the Fifth Technological Revolution. As if that wasn't enough, Japan recently propagated the transition of the country towards Society 5.0, where smart technologies will raise socioeconomic development to a whole new level. According to Wilenius and Casti (2015) the same technologies will soon trigger the Sixth Revolution. Their unlimited potential might lead up to and beyond a critical point, known as "technological singularity", with artificial superintelligence taking over from humans the control of technological evolution and socioeconomic development.

While each of the above concepts may be questioned, they all direct attention to countless (irreversible) changes in production, employment and everyday life.

Although the future is never certain, as the two quotations above emphasise, this does not mean that we cannot say anything about it. In fact, today we know things we did not know in the past. The arguably most important of them is the fact that the Western Antarctic Ice Sheet is now subsiding into the sea at an accelerating rate. There are good reasons to presume that this process is irreversible, and that rising sea level will have a huge impact on coastal areas worldwide, triggering potentially catastrophic changes of earth's climate, mass migration, and other undesirable consequences.[1] Most are due to anthropogenic causes. This flies in the face of an idea, advocated with almost religious zeal by many if not most economists, namely that if individuals are left to their own devices, the economy will self-organise into a state that has satisfactory welfare properties. As Andrew Schotter (1985, p. 2) put it: "nothing but selfishness is necessary to yield socially beneficial outcomes." Climate change provides compelling evidence that this is not generally the case. The complex dynamic and adaptive system has passed a threshold, or critical point, beyond which its behaviour is not only quantitatively, but qualitatively different. The way back into a "safe" area, in which there is stability, is blocked, at least for now.

Climate change and the prospect of machines taking over are the unintended consequences of the success of what Joel Mokyr (2016) called a "culture of growth". The corresponding climate of innovation developed in Europe which made the (First) Industrial Revolution sparked a remarkable period of growth in per capita income and improved living conditions. Yet the economy is not only a sort of machine that solves problems, it also creates new ones. "Necessity is the mother of invention", the old saying goes. Will the necessity be large enough to generate a sufficient flow of inventions, and will these inventions themselves lead only to challenges and risks that are manageable?

We do not pretend to be able to answer this question. Instead, we will limit ourselves to discussing some of the outstanding features of the new wave of innovations discussed above, how they compare to similar waves in the past, how economists have attempted to understand and deal with them, which concepts and tools they have developed to do so, and what are some of the most significant effects these innovations can be expected to produce.

In this paper we will deal with a range of important issues. In Section 2 we discuss some of the more difficult and frequently overlooked problems in analysis. Section 3 offers a brief description of a few concepts and tools widely used in the theory and empirics of technological change. Section 4 provides the nutshell history of mankind in terms of the long-wave theory introduced by the Russian economist Nikolai Kondratieff, which Joseph Schumpeter suggested naming "Kondratieff waves" in his honour. Section 5 takes a closer look at the special characteristics of the new technologies under discussion here. Section 6 deals with some of the expected effects of smart technologies and is subdivided in three parts. First, we discuss the impact on labour, employment and wages, then turn to firms, profits and market forms, concluding with some observations on how this will affect the public sector and the state. The concluding Section 7 asks with reference to Schumpeter's concept of "creative destruction", whether the innovator, who causes both creation and destruction, should compensate the losers in the interest of fairness. This would allow for a relatively smooth absorption of the new and effective exploitation of the opportunities it offers. The inclusive approach suggested seeks to respect Francis Hutcheson's 1726 principle of "the greatest Happiness for the greatest Numbers".

2. Difficulties of the analysis

In the media we all keep running across statements like these: Digitalisation will churn *x* per cent of the jobs currently available in country *Y*. It will increase labour productivity by a factor of *z*. Many of these so-called forecasts lack any mention of the time period and details about how this is supposed to happen. Yet if, for example, fifty per cent of the current jobs were to become redundant, it would make a huge difference, whether this will take place during the next five or the next fifty years. Clearly, only very few jobs will be affected on short term, whereas in the long run nearly everyone will. Hence statements such as those mentioned above amount to little more than vapid chit-chat. They do, however, often activate or appease people, and this frequently seems indeed to be intended by those making these statements.

This is not to belittle the difficulties of predicting the probable course of future events due to new waves of technological change. It is therefore appropriate to begin this essay with a brief account of the most important problems we see. Economists (and people in general) should be made aware of the "pretence of knowledge" (Hayek).

First, it should be clear that the further one looks into the future the greater the uncertainty. Technological progress is not a one-time event, but an ongoing process that will continually lead to new methods of production, new products and new forms of organising the labour process, which are beyond anything we can predict with any degree of reliability. The assumption of complete foresight upon which some economic models are based, while making the life of the economist a lot simpler, and which may, with due caution, be employed for heuristic purposes, must not be taken (too) seriously. For example, what can we know today about the possibilities and limits of artificial intelligence? What about its rate of diffusion throughout the economic system? What about other breakthroughs in technology and the material sciences? And the list goes on. We may at best agree on qualitative statements about probable economic, social, cultural and political effects and perhaps use models, and it is useful to apply scenario techniques to delineate corridors within which the actual development will presumably take place.[2] This may somewhat "tame" the uncertainties we are confronted with, but it cannot entirely do away with them.

Secondly, the way people perceive problems can prompt different responses, which in turn can change the course of events. Ideally, we would like to be able to predict both the technological stimuli and the political responses they engender with some degree of certainty in order to reach informed conclusions about the "seamless whole" (Georgescu-Roegen) of the dynamic process. However, we know very little about how politics will react and how these reactions will be received by society. Again, scenario techniques may help, but their contribution must remain limited.

Thirdly, what we can observe through time are multiple effects that have multiple causes, and effects can frequently themselves cause further effects. It would be folly to presume that we can observe all causes and effects that are at work here. Therefore, the real question is: Which causes lead to which effects? This is known as the imputation problem. Given the limited visibility of causes and effects, answers must necessarily be incomplete and provisional. In this paper, we will focus our attention on what we consider to be the most important causes and effects we find most relevant and largely ignore the rest. Identifying, selecting, and attributing these cause and effect relationships will be a challenge. For example, the time path of overall employment or the employment of a particular kind of labour reflects not only the impact of digitalisation, but may also depend on innovation in other areas, as well as economic policy decisions, the state of the world economy, on globalisation, natural catastrophes, political upheavals, and armed conflicts, just to name a few. Digitalisation is usually seen as a prime culprit, but hardly any serious attempts are made to take the imputations seriously. There can be no doubt that this is a tricky problem that will call for a few rough and provisional answers, but to ignore it entirely is out of the question.

Fourth, there is the widespread view, both in the popular and scientific literature, that the past provides a good guide to the future. When, for instance, there has been no considerable "technological unemployment" in the past, can it safely be assumed that there will be none in the future?[3] As David Hume insisted as early as 1740, we cannot infer on the basis of past evidence a general law that applies for all upcoming developments. This is known as the problem of induction, which, alas, is almost universally ignored. Hume's view is supported by dynamic economic theory. As has already been mentioned, complex dynamic, adaptive systems typically exhibit threshold or critical points of certain variables, which, if passed, lead to a change in the behaviour of the system. Beyond such a point things behave differently. Will artificial superintelligence (ASI) mark such a critical point, at which artificial intelligent agents surpass humans, upgrading themselves technologically at an accelerating speed?[4] Beyond this point humans, by definition, lack the capacity to fully grasp what is going on and lose all control over human civilisation. Some highly respected scientists, such as the late Stephen Hawking, even feared the end of mankind. Compared to previous waves of innovation, will this time be fundamentally different?

Fifth, and finally, many economic processes are subject to circular and cumulative causation. Foreshadowed in the writings of the classical economists, especially Adam Smith, the concept was developed by Gunnar Myrdal and further elaborated by Nicholas Kaldor. The basic idea is that one change in the economic system will trigger other changes, where these changes are circular and yield economically positive or negative outcomes – they are "virtuous" or "vicious". The direction they take and the speed at which their effects can be discerned are frequently difficult to anticipate. This is in no small degree responsible for the complexity of the subject and can be expected to remain so or even gain in importance in the future. The reason is that in the digital economy, economies of scale and network effects are joined by new efficiency and productivity enhancing feedback loops due to robots and algorithms in data rich markets. This increases the complexity of the system as a whole. Paradoxically, they also lead to its rapid decrease in transparency, despite the growing mass of data available.

These phenomena can lead to unintended consequences of human action, a doctrine which was especially advocated by representatives of the Scottish Enlightenment who experienced the transition from a largely static state of socio-economic affairs to a progressing one. Adam Smith coined the famous notion of the "invisible hand" to describe the fact that, while people typically act in accordance with their perceived interests, their actions often entail effects they neither intended nor foresaw; that they could in fact never have possibly foreseen. These effects may be beneficial to society as a whole, or they may be quite the opposite. It is the task of political economy, the "science of the legislator", to suggest institutions and regulations that foster the wellbeing of its citizens and ward off dangers. The quality of such institutions and regulations has an impact on the direction and effects of technological change.

While an analysis of technological change and its impact on the economy and society is intrinsically difficult, we have today a number of concepts, tools and analytical instruments that help us to anticipate what might come which we will now briefly describe.

3. Concepts and tools used in analysing radical technological change

Ever since the inception of systematic economic analysis at the time of the classical authors, economists were keen to understand the emerging new world that was unfolding before their eyes, and to elaborate concepts and tools with which to capture and describe these phenomena. For a brief summary of what has been accomplished in this regard, see Haas et al. (2016). Here we will focus our attention on salient features of contemporary technological trends and the way they are tackled in economics.

Robotics and AI are advancing at a staggering rate. The number of industrial robots, for example, tripled between 2002 and 2014 (IFR 2015), and AI has almost unknowingly become a fixed part of our daily life.[5] According to Mark Weiser (1991, p. 94), chief technologist at Xerox PARC in the 1990s, "the most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it." Herein lies the blessing of new technologies when they seamlessly extend and transform human experience; but also their curse, when they gradually undermine the most fundamental rules upon which society is based, such as the right to privacy or the right to work.

Weiser's statement hints at an aspect of radical innovations, namely their potential to cause disruptive technological change that affects the entire socio-economic system. It doesn't really matter what specific purpose they were created for; they can in fact impact entirely different areas of technology, ranging from material technologies (e.g. biotechnology), energy (e.g. electricity) and information and communication technologies (e.g. computer) to tools (e.g. wheel), transportation (e.g. automobile) and organisation (e.g. factory system).[6] What matters is the generality of their purpose – their versatile applicability. In the literature, these disruptive technologies are covered under different labels, such as "generic technologies",[7] "enabling technologies"[8] or "general purpose technologies".[9] Over time, the general purpose technology (GPT) concept has increasingly gained ground in the scientific community, not least because the seminal paper by Bresnahan and Trajtenberg (1995) gave rise to a series of formal models that link GPTs to economic growth and distribution.[10]

These models all reflect the three fundamental features of a GPT:[11]

(1) It is widely used.

(2) It is capable of continual improvements.

(3) It enables innovations in application sectors.

Thus, the widespread use and broad applicability of the technology implies that each sector has to tailor it to some extent to its own needs and wants, and this continuously, as the GPT improves over its lifetime. The productivity gains associated with technical progress in the GPT-producing sector and its application sectors (i.e. characteristics (2) and (3)) are described as "innovational complementarities". Aside from pervasiveness and technological dynamism, Bekar et al. (2017) further stress the non-substitutability of the GPT: One technology cannot be replaced by another without fundamentally altering production throughout the economic system. Without ICT, hardly any production process currently operated would work anymore.

The emergence of a GPT does not instantaneously imply a technological revolution. AI, for example, was already discussed at a conference at Dartmouth College in 1956. At that time, scientists were aware of the huge potential underlying this technology, but its development was constrained since badly needed complementary technologies, such as powerful and economical computers, were not available.[12] Only recently AI has drawn much attention, due to far-reaching advances in key areas such as machine learning, pattern recognition and natural language processing. Nowadays, it is heralded as the next GPT[13] by a group of 30 leading social scientists who set up a novel research agenda: the "Economics of AI". Nonetheless, these experts also point out the speculative nature of the present discussion, given that the GPT has not yet diffused widely.[14]

The example of AI shows that a technology cannot be identified in general as a GPT ex ante, i.e. at the stage of invention. Only once it has become a marketable invention, such as AI embodied in smart phones, and has diffused over large parts of the socio-economic system, its impact on the economy, society and culture becomes visible. This is the reason why most of the ideas about radical technological change[15] are based on ex-post rationalisations of historical events (linked, for example, to the emergence of the steam engine, electricity, or ICT), whereas the first generation of GPT-models[16] rely on the assumption that a GPT is identifiable as such already upon its arrival.[17] Not even AI itself, with its subfield of machine learning used to predict future outcomes based on big data, can help to solve the inherent unpredictability of its own technological evolution and economic success and the socio-economic transformation processes it triggers.

Due to the pervasiveness of GPTs, their widespread use leads to adjustment processes that affect far more aspects than just the production side; they also have profound effects on society and culture. It is therefore crucial to study these technologies as a particular and distinct phenomenon that differs in terms of causes, characteristics and consequences from mere incremental innovations that continuously feed economic development. This view is by no means a new narrative in economic analysis: In his Business Cycles (1939), Schumpeter linked major innovations to so-called long waves of economic development, also known as Kondratieff-cycles.[18] These are characterised by cyclical movements of prices and economic activity within a time span of around half a century. Schumpeter was predominantly interested in explaining reasons for the emergence of long waves of development. According to him, contemporary economic analysis – the reference is to Walras's theory of general equilibrium – was trapped in a static framework and failed to understand the dynamic nature of the capitalist economic system, its inherent restlessness.[19] Competitive conditions force firms to innovate and people, whose main talent consists in their ability to select from the stream of inventions those that can be marketed profitably, that is, entrepreneurs, will shake up the economy. They are seen to propel the evolution of the socio-economic system by generating new business opportunities, and competitive pressure forces other producers to improve upon or imitate them.

The resulting "swarms" or clusters of innovations create new and rapidly growing sectors, lead to capacity expansion and structural change and cause the upswing of the economy.[20] However, this bandwagon effect does not last indefinitely, as the entry of new firms continuously drives extra profit margins down. Firms which do not innovate or imitate successfully will sooner or later have to leave the market and succumb to the forces of "creative destruction" (Schumpeter [⟨1947⟩ 2003], p. 83). As the new opportunities are exhausted, extra profits vanish and investment is directed elsewhere, ringing in the downswing phase of the cycle. According to this theory, economic development inevitably proceeds via a series of ups and downs or leaps and bounds, reflecting inter alia the whole lifecycle of the technology – from its crude beginnings over its improvement due to follow-up innovations up to its maturity.

Kondratieff cycle theory has been highly disputed among economists ever since its proposal, especially regarding their periodicity[21] and the question as to what exactly causes the fluctuations in economic growth.[22] A less rigid notion than cycles possessed of a well-defined pattern are long (or K-)waves, which will be discussed in Section 4 below. With respect to the particular causes, Schumpeter's view was further elaborated by Mensch (1975) who distinguished between basic innovations and improvement innovations, the former being the primary drivers of long waves; while Freeman et al. (1982) emphasised the role of the adaptation to and the diffusion of technologies in spurring the economic upswing.

Determining the starting point of a long wave is easier than the end point, as one can identify in retrospect the most important (cluster of) innovations and the time of their invention, but less so the time when they stop being the engine of economic growth. Thus, the period of a long wave is assumed to coincide with the lifecycle of the technological breakthrough that triggered it. However, this does not imply that at the same time the leading sectors of the technological transformation become insignificant. They rather compete with the newly emerging industries linked to the next technological paradigm, before surrendering to the forces of creative destruction (see, e.g., the case of steam power vs. electricity); or they remain important in the next K-wave because they enable the new technology (as it was the case of electricity for ICT). Thus, structural change follows a different time pattern than the lifecycle of a GPT characterising a particular K-wave; or, in other words, industrial revolutions usually span more than one technological revolution – they are driven by co-existing GPTs, each of which is typically at a different stage of its gestation period.

Technological change affects the distribution of income and wealth. Currently we can observe two trends, in particular: (i) a growing discrepancy in profitability between "superstar firms", on the one hand, and ordinary firms, on the other, and (ii) a growing dispersion of wages among workers with different skill levels. We owe David Ricardo the important discovery that any system of production, or technology, is characterised by a constraint binding changes in the various distributive variables.[23] While Ricardo's focus was on the inverse relationship between the competitive rate of profits and the share of wages, a more general version distinguishes between differential rates of profit and differential wage rates. What we will call, for short, the "distribution function", may then be written in implicit form (if certain conditions are met). In the simple case in which there are only two industries – one monopolised by a superstar firm, the other competitive – and two skill levels – high and low – we have

$$\phi(r_s, r_o, w_1, w_2) = 0.$$

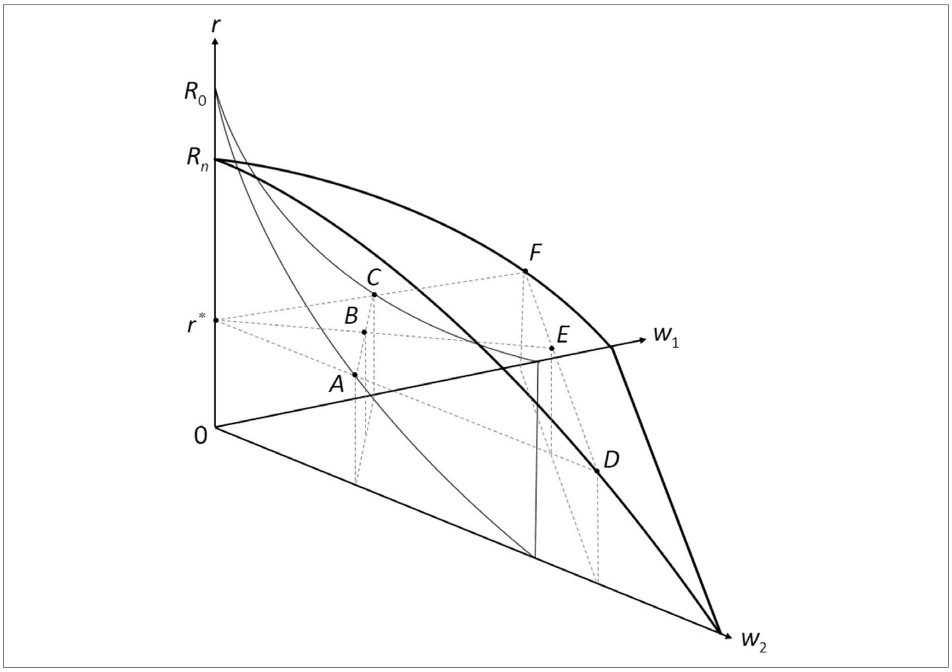
Here r_s is the rate of profit of the superstar firm, r_o is the general rate of profit of ordinary firms (where $r_s > r_o > 0$), w_1 is the wage rate (in terms of some bundle of commodities) of workers with low skills, w_2 is the wage rate of workers with high skills (where $w_2 \geq w_1 > 0$).[24] For a given system of production, any two distributive variables are inversely related to one another, given the levels of the other variables. The distribution function thus defines the set of all possible constellations of the distributive variables compatible with the given system of production.

Technological change may be seen as establishing a sequence of new distribution functions, each one replacing the preceding one. A comparison between any two such functions allows one to distinguish between different forms of technological change. In illustrating the basic idea graphically, we are confined to three-dimensional space: we can either start from a uniform rate of profits, r, and allow for differential wage rates, or start from a uniform wage rate, w, and allow for differential profit rates. Figure 1 refers to the former case. The finely drawn graph reflects the system of production prior to a given technologically-induced change and the heavily drawn one following it. In this case, both types of labour have become more productive, which can be inferred from the fact that the intercepts of the heavily drawn graph with the two axes along which the wage rates are measured are located at a greater distance from the origin: the maximum wage rates compatible with the new technology are larger, and the percentage increase of productivity of work of type 2 is larger than that of work of type 1. It thus exemplifies a form of skilled-biased technological change. At the same time the maximum rate of profits decreases from R_o to R_n, which expresses the fact that the technological change is capital-using.

For a given rate of profits r^*, the line AC gives all combinations of the two wage rates compatible with the old technology, whereas the line DF gives those compatible with the new one. An increase in r from its original value r^* implies that the options for wage increases are getting more constrained. If average wages increase by less than average labour productivity, the share of wages in national income falls. Moving in the diagram from a point on the lightly drawn envelope to one on the heavily drawn one (or, more generally, between different numerical configurations of the two distribution functions) allows one to mimic developments in the real economy, such as rising wage inequalities, profit rate differentiation because of the monopolisation of industries and the like (see below, Section 6). Of course, an explanation of any particular movement requires additional arguments: the functions only define the possibility spaces.

This argument should make clear that a partial analysis is inappropriate when we are confronted with GPTs and the radical and possibly disruptive socio-economic changes they engender. A general analysis is required that takes the interdependencies between industries and economic activities seriously.

Figure 1: Systems of production before (finely drawn graph) and after (heavily drawn graph) technological change



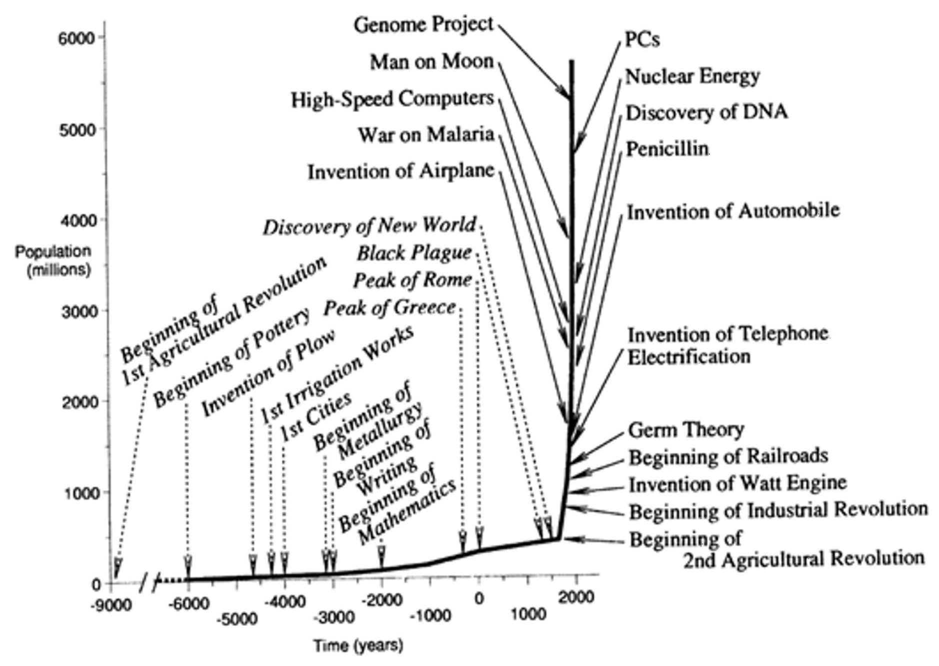
Next we turn to a brief account of the socio-economic and technological history of mankind, which serves the purpose of putting present-day developments in historical perspective and identifying its distinguishing features.

4. The history of mankind in a nutshell

The following Figure 2 taken from Fogel (1999) contains a most impressive picture of human history that relates the growth of population on earth and important inventions and innovations. It highlights the dramatic change that took place shortly after the discovery of the so-called "New World" and shortly before the beginning of the 2nd Agricultural Revolution and the (first) Industrial Revolution. The illustration makes clear that the history of mankind has always been strongly interwoven with discoveries, inventions, technological and organisational change.

The Neolithic (or First Agricultural) Revolution starting around 9000 BC transformed human societies from making a living by hunting and gathering to settlement and farming. The invention of cuneiform writing in Southern Mesopotamia around 3000 BC and especially the invention of mathe-

Figure 2: The growth of world population and some major events in the history of technology



Source: Fogel (1999) 2.

matics a millennium later were of the utmost importance for all further developments, technological, economic and other. For millennia population increased only slowly, if at all, and this continued almost until the mid-14th century, when the black plaque eradicated a big part of the population in Europe.

The invention of letterpress printing in 1440, the discovery of new continents around the turn of the century plus a range of further inventions heralded the Modern Age. In Britain from the 16th century onwards the 2nd Agricultural Revolution took place, which brought new farming systems such as novel forms of crop rotation, a greater use of tools and equipment and a more effective drainage. These technological advances boosted agricultural output and food production and brought an acceleration of population growth plus rapid productivity increases.[25] While prior to the 2nd Agricultural Revolution the pace at which novel technologies and other innovations pervaded Europe's societies was relatively modest, technological change since then picked up considerably, as did the rate of socio-economic transformation that accompanied it.[26] Significant medical progress contributed to lower infant mortality rates, positively affected population growth and markedly increased life expectancy.

The 2nd Agricultural Revolution was a catalyst of the Industrial Revolution, which during the second half of the 18th century marked one of the most disruptive eras in economic history. The emergence of the steam engine set off a series of K-waves, each reflecting a different technological paradigm. These technological revolutions did not only lead to a transformation of the prevailing technology base and system of production; it had also a significant and thorough impact on social, political and cultural life.

The first K-wave (c. 1770-1840) saw an impressive rise of three sectors: coal, iron and textile (cotton cloth). By means of Watt's condensing steam engine invented in Britain in 1769, iron could be produced more efficiently, boosting the exports of the sector and the economy as a whole.[27] The steam engine also provided a greater flexibility in the choice of location and therefore induced a more efficient (re)location of economic activity according to the proximity of markets and input factors such as labour and coal. This in turn fostered industrialisation and urbanisation and stimulated economic growth.[28] Further inventions led to the mechanisation of cotton cloth production and the rise of the British and fall of the Indian textile industry.[29] This stimulated innovation in (iron) machine tools. It also left a strong mark on the structure of the work force: Depending on the specific work tasks, the utilisation of the steam engine in production increased or decreased the skill level of the labourer. In terms of its socio-economic consequences, population growth again accelerated remarkably through improved living conditions – Britain's population on average became healthier, better fed and educated.

The steam engine eventually also brought about a new mode of passenger and freight transport: railways. After overcoming initial problems, railway construction, leveraged by a strong iron industry, experienced a take-off in the 1840s, triggering the second K-wave (c. 1840-1890). Railways became the dominant means of public transport in Britain, but also in the U.S., Austria and France.[30]

The explosive population growth and the socio-economic changes during and as a consequence of the Industrial Revolution also raised concerns and triggered an occasionally heated debate amongst economists and social philosophers. Thomas R. Malthus in 1798 published the Essay on the Principle of Population.[31] Disputing the ideas of the Enlightenment and of the Baconian programme, he outlined a theory of population that thwarted the promise of bettering the human lot by means of technological progress. According to Malthus, human progress faces an irremediable conflict between population growth, on the one hand, and the growth of food supply, on the other. Due to diminishing returns in agriculture, food supply grows at a smaller rate than population potentially does, which is reflected in recurrent famines and periods of misery.

Malthus's techno-pessimistic outlook was disputed inter alia by David

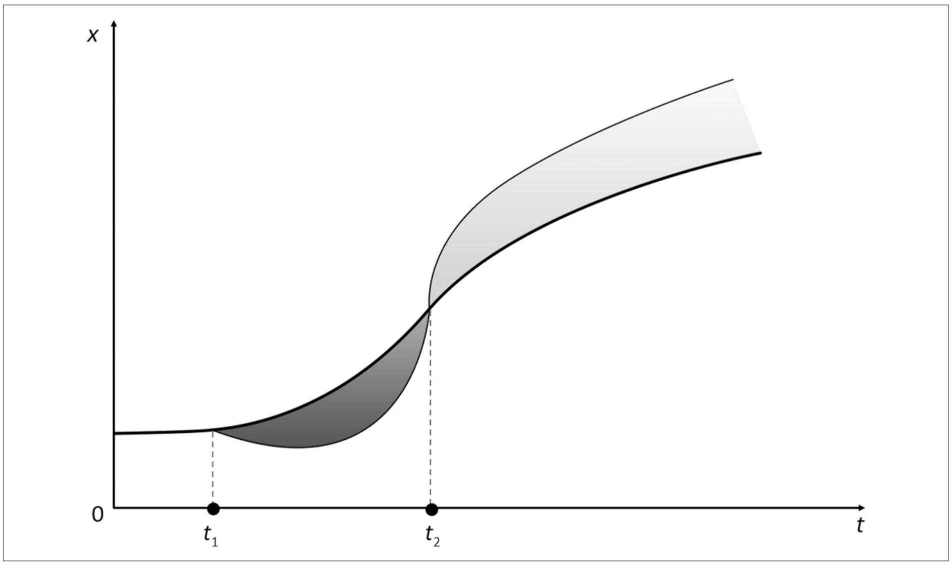
Ricardo, Charles Babbage and others. However, their opposition to Malthus's doomsday economics did not mean that they were of the opinion that aside from temporary adjustment problems technological change was always a universal blessing and was never accompanied by considerable side effects that are detrimental to some classes of society. Being attentive students of the epochal change the first machine age brought with it, they saw that the introduction and diffusion of any new technology typically has both winners and losers. It brings about new tasks, jobs, firms and entire industries, but it also eliminates some of the old ones. At the beginning of the 19th century in England the Luddite movement – weavers, textile artisans and workmen – protested against their poor working and living conditions and destroyed machinery which was seen to take away their jobs. The Luddite movement and the uprising of the Silesian weavers are famous examples that vividly bear testimony to the human fear of technological change seriously injuring workers' interests. The pros and cons of technological change and its effects on employment, wages and living conditions were intensively, and controversially, discussed at the time of the classical political economists. In 1821 John Ramsay McCulloch published a theory of automatic compensation of any displacement of workers due to the employment of improved machinery. A devoted follower of Ricardo, he felt that his theory expressed in a faithful way the latter's view on the matter. To his great disenchantment Ricardo at around the same time fundamentally revised his previous opinion. In the third edition of his Principles published in the same year he added the famous chapter 31, "On Machinery", in which he argued that a particular form of technological progress "is often very injurious to the interests of the class of labourers" (Ricardo, Works I, p. 388). The form he had in mind involved the replacement of human labour by machines and thus an increase in fixed capital intensity and in labour productivity. He illustrated the case in terms of a judiciously chosen numerical example, which shows that labour displacement cannot possibly be compensated in the short or medium run. It may be compensated in the long run, if an increase in profitability happens to sufficiently speed up capital accumulation.

Figure 3 illustrates what has just been said. x represents total employment and t time. The thick curve gives the development of the system in the hypothetical case without technical change and the thin curve the equally hypothetical one with technical change. In the case depicted, the introduction and diffusion of the new technology starting at time t_1 is at first accompanied by a net loss of jobs compared to the reference path without technological change. At time t_2 the system is taken to catch up to the latter's employment level and thereafter to exceed it. The darkly shaded area gives the comparative overall loss in employment between t_1 and t_2, the lightly shaded area the overall gain from time t_2 onwards. In the case under consideration, there is no problem in the long run, but there is one in the short and medium run, which may expose workers and their families to a significant worsening of their living conditions and society to a serious stress test. In case there is a sequence of technical changes of the kind discussed, it cannot even be excluded a priori that net job losses will become a persistent phenomenon.[32] It is interesting to note that Ricardo as early as 1821 even contemplated the virtual end-state of the process of mechanisation that gained momentum before his eyes – a fully automated system of production and its effects:

> "If machinery could do all the work that labour now does, there would be no demand for labour. Nobody would be entitled to consume anything who was not a capitalist, and who could not buy or hire a machine." (Ricardo, Works VIII, pp. 399-400)

In the digital era the problem Ricardo raised some two hundred years ago is on the agenda again.

Figure 3: Development of employment (*x*) over time (*t*) without (heavily drawn graph) and with (finely drawn graph) technical change



Ricardo's machinery argument sparked widespread controversy involving, among others, Karl Marx and Knut Wicksell. The former radicalised the argument by insisting that the form of technological progress Ricardo had analysed was the dominant form in capitalism, whereas the latter argued that falling real wages might mitigate the employment problem somewhat via input substitution, but could not overcome workers' losses in real income. Wicksell therefore recommended workers to migrate from Sweden to the United States and other countries in order to escape their deteriorating situation at home.

Without denying or belittling these negative aspects of recent social and economic history, it must be said that the Industrial Revolution was eventually accompanied by a hitherto unknown increase in real income per capita in European societies. Mokyr considers "cultural entrepreneurs" such as Francis Bacon, Adam Smith or Martin Luther – people who "think outside the black box" (2016, p. 60) – as having played a major role in this regard as they successfully imposed on society their new and path-breaking ideas and beliefs, which via a "market of ideas" got quickly disseminated. They considered the betterment of life of people in general as possible and desirable and instilled the belief that "material progress would consist of practical advances relying on the growth of useful knowledge" (ibid., p. 259).

The invention of the dynamo by the end of the 19th century heralded a new era of rising prosperity – and the third K-wave in history (c. 1880-1940). The latter was triggered by electrification and the change in the organisation of production from small-scale to mass production, the pillar of the Fordist Paradigm. Technological advancements in the conversion from iron to steel led to a spike in steel production and also the chemical industry was flourishing, thanks to a by-product of the gas-lighting industry, coal tar, that facilitated synthetic dye materials.[33] Colour chemistry in turn stimulated the rise of the pharmaceutical industry, while electricity enabled the birth of a whole new industry: electrochemistry. However, this Second Industrial Revolution came along with a wave of layoffs and a decrease in skills demanded. The spectre of "technological unemployment" was back again and economists including Schumpeter (1912) insisted that the more radical and disruptive innovations are, the larger the possibly negative immediate impact on the labour force. However, in the medium run the situation can be expected to improve due to an acceleration of capital accumulation and economic growth. Eventually, Schumpeter (1939, p. 754) argued, the dwindling profits in the electric, the chemical and the automobile industries by the late 1920s and early 1930s culminated in the Great Depression. The way towards this hitherto largest economic crisis in history was aggravated by large increases in labour productivity in agriculture that resulted in a rising unemployment and a further reduction in aggregate effective demand.

After the Great Depression, marking the end of the third K-wave, it was the automobile industry that brought the economic system back on track and heralded a fourth K-wave (c.1940-1980), boosting especially those industries that provided complementary goods. As Henry Ford – thanks to the introduction of the assembly line and the possibility of mass production – managed to reduce the costs of cars significantly, individual transport started to boom. Besides, after the Second World War the electrification spurred the production of household appliances and the expansion of telecommunication services. Other sectors also experienced a boom, in particular the chemical and aircraft industry both of which had a pivotal function during the Second World War. The oil crisis in 1973 announced the beginning of the end of the fourth K-wave.

The breakthrough triggering the fifth K-wave (starting around the 1980s), however, had already arrived by that time: the microprocessor developed by Intel in 1971 led ultimately to a Third Industrial Revolution based on new information and communication technologies (ICT). In the decades to follow, computerisation pervaded the whole economy. Mass production, the organisational innovation of the Second Industrial Revolution, gave way to a more flexible organisation of production (and work), which eventually led to the automation of whole production processes. In order to foster the adoption of ICT, governments launched mission-oriented innovation policies.[34] Public institutions have played and continue to play a crucial role in the regulation of data use and data security. At the moment we are experiencing, according to Perez (2013), the painful restructuring process after the burst of the IT-bubble in 2000 and the aftermath of the global economic crisis of 2008, both events marking the maturity phase of the fifth K-wave.

The history of technological change shows indeed some regularity in the emergence of technological breakthroughs at the downswing or the bottom of a long wave. Is this evidence enough to base predictions on? If so, the sixth K-wave is likely to start any time soon.

5. Smart everything

Since the launch of the first iPhone in 2007, "smart" has become a catch-all term to describe the properties of key technologies enabling the digitisation of information.

According to the public debate, it is only a matter of time (and of follow-up innovations in this field) until these technologies will have pervaded the socio-economic system, triggering an era in which "computers and other digital advances are doing for mental power […] what the steam engine and its descendants did for muscle power" (Brynjolfsson and McAfee [2014], p. 8). The idea of a new wave of innovations that will in particular transform the manufacturing sector can actually be found already much earlier in the scientific literature. As early as 1981 the French economist André Piatier (1981) saw the society on the brink of a fourth industrial revolution, and Yoshikawa (1995) expressed the need for a "manufacturing renaissance". Both authors stressed the relevance of "intelligent" or smart technologies in this regard. The persistent drawing of parallels to the (First) Industrial Revolution is, not least, ignited by the expectations and hopes associated with the upcoming transformation: The long-desired arrival of a sixth K-wave,[35] sweeping away the spectre of stagnation and washing up a new era of prosperity for industrialised countries.

Given the speed at which inventions are nowadays entering the market, it feels like we are not only facing a new long wave, but rather a tsunami of technological transformation, characterised by a bundle of novel and disruptive breakthroughs mainly from the mechanical (e.g. advanced robotics, 3D printing), the digital (i.e. blockchain technology, big data and advanced data analytics, the platform economy ⟨e.g. AirBnB, Uber, Amazon⟩) and the biological area (e.g. synthetic biology, genetic engineering). It is safe to say that all these technologies are based or depend on digitisation, the conversion of information from analog to digital data. Brynjolfsson and McAfee (2014, p. 79) go as far as to call digital technologies "the most general purpose of all". These own their widespread adoption to the fact that computing power has persistently become stronger and cheaper during the past 40 years. This underpins the remarkable accuracy of "Moore's law" in 1965, according to which the number of transistors that fit on an integrated circuit doubles roughly every two years, or, in economic terms, that the computing power one can purchase with one US Dollar grows each year by a factor of 2.[36] Due to the radical evolution of micro- and nanoelectronics during recent decades, the miniaturisation of components to the micro- and nanoscale even outperformed Moore's law in the sense that the computing power has actually doubled every 1.5 years (captured by the term "More Moore"). At the same time, endeavours in this technology field have also been directed towards the integration of diversified (digital and non-digital) technologies in order to increase the functionality of a semiconductor-based device (coined "More than Moore").[37]

Together, these technological milestones have paved the way for the world we are living in right now: One that is ruled by smart technologies that "enabl[e] intelligence, processing, communication, and networking capabilities in all products, systems, and processes, influencing all parts of society".[38] Not least, they generate cyber-physical systems (CPS) which map the real world into the cyber world: Physical processes are being monitored and controlled by embedded computers and networks (cyber). CPS usually comprise feedback loops which enable self-learning, e.g., a machine that maintains and repairs itself based on the performance monitored by sensors and sent to a computer. They will be an essential part of the dawning second machine age where machines will communicate autonomously (machine-to-machine interaction or M2M) via the internet ("Internet of Things"), and enable the production of knowledge-intensive, but still tailor-fit products on a large scale (mass customisation). The huge amount of data generated in this course relies heavily on a well-developed digital infrastructure that allows the employment of cloud services.

While these technologies initially revolutionised in particular the organisation of production in manufacturing, they by now have become an integral part of the service sector as well: think about the employment of robots to complete orders placed online and the utilisation of drones to deliver those packages. Smart transport further includes the optimisation of freight routes (by means of advanced data analytics) and will not far into the future also involve self-driving vehicles. Blockchain will subvert the current organisation of the banking and finance sector by simplifying international transactions (smart contracts) and increasing the speed and transparency of financial services. Beyond, More-than-Moore technologies may also contribute to solving the most urgent challenges of our society regarding, e.g., the changing demography and health, energy and environmental hazards, security, etc.[39]

Smart electricity grids, for example, allow the decentralisation of the energy market and the single household to become a "prosumer", a combined producer and consumer, of electricity. Other applications, such as smart water grids for irrigation, will not only facilitate the sustainable use of natural resources, but will also become powerful tools in the context of climate change adaptation. Disaster risk management (incl. prevention) already benefits from the wide adoption of smart phones that interconnect people in vulnerable areas. Smart technologies will further revolutionise the health and wellness sector by enabling, e.g., wearable health monitoring systems or biosensors for diagnostic purposes[40] as well as new medical tools (such as 3D printing of implants, pacemakers, or even body parts, etc.). In addition, big data will be playing a crucial role in the detection and monitoring of disease outbreaks. Smart technologies will also facilitate daily life: The "connected home" is no longer science-fiction, as smartphones supported by sensors already switch on and off lights, regulate the room temperature, and even monitor home appliances. Sensor technologies allow the management of traffic, logistics, resource use and waste, amongst others, for whole urban areas, paving the way for "smart cities".

However, all these technology trends also constitute potential threats to our personal privacy and freedom and they endanger democracy, as the Russian meddling in the 2016 U.S. election has shown. Cybercrimes (such as data hacking, financial crimes, intellectual property infringement) have increased at a staggering rate, targeting not only governments, but also companies and the ordinary citizen. The huge number of connected devices (projected to amount to 200 billion by 2020) provide a giant playground for hackers and other cyber-criminals. The related costs are estimated to exceed 600 billion dollars or 0.8% of global GDP in 2018.[41]

Governments also invest in these technologies for the sake or under the guise of national and international security. Examples thereof are so-called unmanned combat aerial vehicles (UCAV) – drones equipped with e.g. missiles to carry out air strikes – or other lethal autonomous weapons (LAW), i.e. military robots enabled by AI to execute commands without human involvement.

Many important innovations enabling a smart device, such as the Internet, GPS or RFID (radio frequency identification), actually have their origin in military technologies or are the outcome of other technology programs funded by the public sector, in this case the U.S.[42] The state finances the development of new technologies that strengthen its military power and then allows firms to commercially develop and exploit the new devices. We thus have before us a hybrid form of economic activity, partly public and partly private. The strong mission-oriented policy coupled with a strategy of close cooperation between the state and private stakeholders aims at spurring the leadership of countries in the global technology race, where some in Asia (in particular China, India and the four Tiger states) will in all probability attain a position that might be compared to that of Great Britain and Europe at the time of the First Industrial Revolution and the U.S. at the time of the Second and Third Industrial Revolution.

During the last few years, the Fourth Industrial Revolution has been given high priority by national and supra-national public authorities and in many industrialised countries efforts are undertaken to shape this technology race. For instance, the Europe 2020 strategy is based on seven single flagship initiatives one of which, the so-called "Digital Agenda" as of 2010, was exclusively designed to foster the digital economy and society across Europe.[43] Embedded in the more comprehensive Europe 2020 strategy, the Digital Agenda should contribute to the overarching goal of securing smart, sustainable and inclusive future growth in the European economy. Other examples are the "Strategy for American Innovation" that was implemented in 2009 and updated several times under the Obama-presidency. This policy initiative has a strong focus on innovation policy in a Schumpeterian tradition as it declares innovation as the precondition for long-term economic growth and competitiveness.[44] Moreover, China in 2015 put forward the state-led initiative "Made in China 2025 (MiC-25)" which aims at the technological catch-up and upgrading as well as modernisation of its industrial production and its whole economy.[45] In line with several other state-led policy strategies, such as the 13th 5-year plan, the SEI-initiative or the National Innovation-Driven Strategy Outline, MiC-25 prioritises ten key areas, including energy-saving and new energy vehicles, high-end computerised machines and robotics, agricultural machinery and equipment etc. Also, Japan, Singapore and South Korea have recently adopted systemic policy approaches aimed at preparing their economies and societies for the digital transformation. Japan in 2016 has launched "Society 5.0" that seeks to establish a completely networked

Japanese society. Singapore, already two years earlier, introduced "Smart Nation", a fairly visionary and techno-optimist policy initiative that pushes the adoption of new ICTs, big data and innovation in other digital technologies across all parts of society. Moreover, it addresses socio-demographic challenges that Singapore currently faces, such as an ageing population. Different from these holistic approaches, the South Korean policy initiative "Manufacturing Industry Innovation 3.0 strategy", implemented in 2014, focuses attention on the development of digital and computer-related technologies in its production sector.

In a nutshell, the state encourages new technologies and new products and enables innovating firms to establish technology platforms. These are designed to differentiate their products and build up customer loyalty. The protection of patents and intellectual property rights by the state and its institutions, however, also safeguards the trend towards oligopolies and monopolies (further discussed below, in Section 6.2).

As humanity is thus pulling more and more out of the loop in which smart machines operate and interact, and artificial agents[46] are projected to become fixed parts of our society, the question arises how to monitor and control systems that outperform us in both cognitive and physical domains.[47]

Satisfying answers are urgently needed, given the widespread anxiety that the seemingly unlimited potential of such systems might lead to technological singularity where artificial superintelligence will autonomously shape technological evolution and thereby socio-economic development. Therefore, these mission-oriented policies are crucial not only for boosting innovative activities, but also dampening the negative by-products of technology adoption in these key innovative areas. This concerns particularly the labour force, but the diffusion of smart technologies also raises other issues that affect the economy and the society, as discussed in the next section.

6. The impact of new technologies on the economy and society

The "race against the machine" (Brynjolfsson and McAfee [2011]) is under way in the work place, in the economy, but also at the global level in terms of an intensified rivalry among innovating countries, competing for technological leadership.

6.1 Jobs, skills, tasks, employment and wages

Machines, Ricardo maintained, are "mute agents" of production that are "in constant competition" with workers. Many modern machines, unlike their predecessors, are self-teaching – in effect able to learn from experience – and are able to communicate with one another via the Internet of Things; they give orders and obey commands from other machines; they are self-controlling and self-repairing. Unlike humans, they need no sleep or rest. The fear that robots and smart machines will destroy human jobs, lead to persistently high levels of unemployment and contribute to rising income inequality in the digital economy is widespread. Do past events, as they were discussed in Section 3, prove these fears to be baseless? Was and is "technological unemployment" simply a chimera, and is there no need to worry about the employment effects of new technologies? The following discussion addresses some of the crucial aspects encountered when studying the issue of technological change, (un)employment and income (in)equality in light of the current technological breakthroughs in smart technologies.[48]

First, when trying to judge whether technological changes, and in particular those associated with smart technologies, do more harm than good to the labour force, it is essential to distinguish a long-term from a short-term perspective. Guesstimates[49] about the extent of job losses and statements about the disappearance of whole occupations are only snapshots and refer to instantaneously feasible technological solutions and artefacts, whereas it is highly uncertain what the future will actually bring in terms of further technological breakthroughs. It should also be clear that what matters from a Schumpeterian point of view is not just the fact of an invention, but whether it can be employed profitably, that is, become an innovation. It is by means of the process of diffusion that an innovation gains economic weight and unfolds its full transformative capacity, leading to structural changes that are the more far-reaching the more radical and disruptive the innovation is.

Second, while technological innovations may destroy jobs, they also create new ones. To get a feeling for whether a given new technology can be expected to lead to labour displacement that outweighs labour compensation, or vice versa, it is essential to look at the production system as a network. In this network, the value chain of a single commodity is not isolated but part of a system of inter-industry linkages both up- and downstream. Thus, from a network perspective and in view of a growing social division of labour, not only the direct labour embodied in the production of a commodity matters, but also the indirect labour does. In short, one ought to be concerned with the vertically integrated labour coefficients and how they develop over time.[50] Several labour compensation mechanisms are distinguished in the literature.[51] However, not only the sum totals of labour displacement and compensation are of interest, but also their time profiles (see again Fig. 3).

Third, a related aspect concerns the ratio of process and product innovations in the current wave of technological change. While process innovations lead predominantly (although not exclusively) to labour displacement due to their productivity enhancing effects, product innovations give rise to new markets, foster additional demand which stimulates employment, and are thus to a large extent responsible for labour compensation. As was stressed and empirically supported by Simon Kuznets (1971), because of satiation levels with regard to the great majority of goods, long-term growth requires new and a growing variety of goods. Can the digital revolution be expected to provide a sufficient number of product innovations, or will it materialise first and foremost in process innovations? Examples of product (and service) innovations in recent years such as the smartphone, autonomous vehicles and electric cars, new medical products and novel goods in the field of biotechnology and neurotechnology, blockchain, digital platforms and social media testify to the potential of the digital revolution to generate new goods. But will this potential be large enough? Several economists and most prominently Robert J. Gordon (2016) express strong doubts. They argue that smart technologies will in all probability fail in this regard and, in comparison to previous technological revolutions, opine that this time will indeed be different. Other economists and especially Joel Mokyr do not share their pessimism: in his essay "Technopessimism is bunk" (which appeared on PBS.org in 2013), Mokyr maintained: "The Digital Age will be to the Analog Age what the iron age was to the stone age."

Fourth, according to the hypothesis of its skill bias, technological change affects the wage distribution between different skill groups by increasing the productivity of high-skilled workers relative to that of low-skilled workers.[52] Recently, skill-biased technological change, favouring high-skilled over low- and middle-skilled labour, has significantly increased wage differentials between various skill groups. However, competition is an evolutionary disequilibrium process in which rival firms are forced to adopt cost-minimising methods of production in order to survive. This development will provide an incentive to firms to also economise on highly qualified, relatively expensive labour and on knowledge-intensive work tasks. Given the rising complexity of smart technologies, we may expect tendencies towards the substitution of machines for those expensive segments of the labour force, which hitherto have been spared from becoming redundant.

Fifth, it obviously matters which kind of jobs and tasks face elimination, and which new ones will enter the economy. In a recent paper, Autor (2015) asks "Why are there still so many jobs?" and argues that "problem-solving skills, adaptability, and creativity" (ibid., p. 5) of human labour cannot (easily) be mimicked by machines. He therefore surmises that medium-income, middle-skill jobs will not vanish quickly as it is currently not possible to unbundle the tasks that these jobs involve.[53] Furthermore, the task and skill content of occupations has already been subject to far-reaching changes in the course of computerisation triggered by the diffusion of the new ICTs since the 1970s. For instance, a study of the U.S. labour market by Muro et al. (2017) highlights the rising importance of "digital skills" for occupations. Between 2002 and 2016 the share of jobs requiring low digital skills decreased from about 56% to 30%, while the share of jobs requiring high digital skills increased from 5% to 23%. Accordingly, the share of jobs requiring medium digital skills rose slightly from about 40% to 48%. These transformation processes can be expected to continue. An important policy issue concerns the matching, or lack thereof, between the need of skills and their provision. The education system will have to bridge the gap and in case it does it badly will be responsible for serious frictions and losses.

Sixth, technological change has long been identified as a major factor affecting the distribution of income and its recent form to be co-responsible for income dispersion (see also Section 3).[54] Apart from personal (wage) income inequality, an important indicator of the balance of power between capital and labour in an economy, and different fractions of them, is the functional income distribution. Technological change has been a major factor in explanations of the sustained decline of the labour share in many countries.[55]

Seventh, workers' bargaining power has significantly deteriorated in recent years, as witnessed by the decline of labour unions. This is due in part to technological change and its impact on the organisation of work (platform or "gig economy") but also because of political efforts to increase "labour market flexibility" via the introduction of alternative work arrangements (such as fixed-term contracts, part-time employment, or contract workers and freelancers) in the constant pursuit of "international competitiveness".[56] Thus, while the sharing out of what may be called the "innovation dividend" requires sufficiently strong labour and trade unions, in fact changes in the labour market induced by digitalisation and policy measures have actually weakened workers' bargaining position.

Eight, growing income inequality and the growing gap between the rich and everyone else is also related to digital transformation. Data-rich markets are characterised by the dominance of a few "superstar firms" that have monopoly-like positions.[57] The rise of these superstar firms is driven by the exploitation of network effects, the establishment of technical standards and barriers, the restriction of their competitors' access to data and the acquisition of promising start-ups. Such business strategies help incumbents to strengthen their market position in the digital economy. The minions of these strategies are shareholders, investors and top executives – hence the top earners – who benefit from the increasing value of dividends, while average workers – at the lower end of the income spectrum – face increasing competition and are more and more frequently forced to accept precarious work arrangements.[58] The dynamic properties of the new technologies bear a great responsibility for the rising concentration of wealth in fewer hands and the ensuing polarisation of society.

Ninth, an increase in formal education alone is unlikely to help fighting wage inequality, if the distribution of digital skills and competences is itself shaped by inequalities. The observation that the access to and the usage of digital technologies are characterised by significant differences between groups of people has been addressed in a vast body of literature on the digital divide and digital inequality, not least in media and communication sciences and sociology.[59] This line of research unveils the structural differences in the access to digital technologies as well as in the ways they are put into use. If structural forms of discrimination remain in place hindering individuals to exploit the digital world to their own benefit, it is not enough to retrain and upskill the workforce in order to battle rising wage inequalities associated with biased technological change. If digital inequality happens to be a problem that affects labour market outcomes as the relevant literature suggests, education policy must explicitly target the reduction of this inequality.

Tenth, one specific facet of technological change rarely considered in economic research is the gender dimension – despite the well-known gender differences regarding employment and education in technology-intensive fields. A recent press release by Statistics Austria (2018) highlights the gender differences regarding the professional use of digital devices. The survey data on ICT usage in households emphasise the importance of ICT in the world of work – in 2018 57% of people aged between 25 and 64 years use computers, laptops, tablets or smartphones for work. However, there are significant differences by gender regarding the quality tasks for which digital devices are used. 20% of men but only 7% of women who use digital devices at work develop and maintain IT-systems or software. This supports Wajcman's (2004, p. 31) observation that "women are chronically under-represented in precisely the jobs that are key to the creation and design of technical systems in the new economy". So even if one looks at the subgroup of people who do use ICT for work, the content of the tasks differs between men and women – with the development of IT and software remaining predominantly in the hands of men. This is in line with research showing that women are more likely to use the Internet to communicate and socially interact with others.[60] As these authors note, from the viewpoint of sociology, this is not surprising since people usually transfer their social roles and interests from the analog to the digital world. This implies that gender stereotyping that takes place offline may appear in "online environments" as well.

6.2 The "wretched spirit of monopoly"

In The Wealth of Nations (1776) Adam Smith time and again deplored "the wretched spirit of monopoly" (WN IV.ii.21) which he believed was constantly seeking ways to abolish competition. Successful innovations establish monopolistic positions and allow the monopolist to pocket extra profits or monopoly rents above and beyond the competitive rate of return on capital. However, Smith was optimistic that as a new method of production or a new good was generally adopted in the economic system, competition would gradually catch up with the pioneering firm, erode its privileged position and reinstall free competition characterised by a uniform rate of return on capital. Interestingly, Schumpeter generally shared this view and insisted that the profits of the entrepreneur, "and also the entrepreneurial function as such, perish in the vortex of the competition which stream after them" (⟨1934⟩ 1949, p. 134). The system is driven in the direction of a new "circular flow", in which the "law of cost" applies again and prices of commodities equal costs of production. In this view monopolies are transient phenomena. This does not apply, of course, to natural monopolies or monopolies granted to a company and protected by the state, such as, for example, the East India Company, which, according to Smith, was a scaring example of the damage that unfettered selfish behaviour could bring about.

Is this time different? It is and it isn't, as the following observations will show. Up until recently the attention focused on the following endogenous factors causing a tendency towards the concentration of market power and monopolisation:

1. Increasing returns to scale that are internal to the firm, also known as the "law of mass production" and cost degression.
2. Economies of scope.
3. Network externalities.

Networks allow the exploitation of scale economies: the attractiveness of a network increases with the number of users ("Metcalf's Law"). The largest network has the best chances to grow and outcompete its rivals. Contemporary examples are online market platforms, social media platforms and computer software. But there is now a further factor at work that is a defining characteristic of the second machine age, the importance of which can hardly be overrated:

4. Feedback loops in artificial learning systems (such as advanced robots, software systems), on the one hand, enable an unprecedented level of self-control by the machine and thus a highly decentralised organisation of production. This in turn strives the cost efficiency of the firm. On the other hand, the amount of data collected and processed by the machine allows the firm to expand its product range and thus opens up new business opportunities.

People who can afford to empower themselves by AI will assume privileged positions. The rise of superstar firms provides ample evidence of the ensuing polarisation of the business world, especially in the field of data-rich markets. These firms are typically characterised by a small staff, a high degree of automation and thus a high capital-labour ratio. They may be compared to an almost unmanned rocket sucking fuel from its environment, which grows and gets more and more powerful whilst flying. Due to the dynamic properties of the technology they use, such firms benefit from rising barriers to entry. They are possessed of a significant advantage for consolidating and expanding their market positions.

Clearly, such monopolies may be endangered by new, path-breaking inventions, but the danger is comparatively small, not least because the huge profits the monopolies pocket can be used to acquire start-ups possessed of the potential of contesting their market power in the future. (Facebook is known to be very active in this respect.) The monopoly may then develop the new technology itself or it may simply remove it from the stage. Market entry of new firms is therefore largely blocked and a functioning competition impeded.

Some further observations should be added. First, the digital revolution brings about the self-transformation of the economic system towards data or digital capitalism, in which data assume two important functions. First, they serve as a kind of new "money" – private information – in terms of which the customer pays the platform firm. (If the collection of data is costly, the platform firm can be expected to charge its customers higher prices for the products it sells.) Secondly, and correspondingly, data are a productive resource that fuels the learning of machines. Data gain in importance relative to labour, land, capital and conventional money and finance. Without too much of an exaggeration we might say: Finance capitalism was, data capitalism is.[61]

Secondly, there are two competing economic coordination mechanisms: the market and the firm. Markets are the realm of freedom and formal equality, in which information flows horizontally, whereas firms are the realm of hierarchy, command and obedience, in which information flows vertically. On the one hand, data-rich markets allow the extension of the market at the cost of firms, and therefore authors like Mayer-Schönberger and Ramge (2017) see traditional firms losing in importance relatively to the market, virtual firms operating in the "cloud" and superstar firms. Evidence- or data-based information together with decision assistants can be expected to improve human decision making, because they overcome to some extent cognitive distortions of agents – complexity aversion, loss aversion, dominance of the negative, confirmation and attribution errors and so on – as they have been analysed especially by Kahneman and Tversky (2000). This should reduce information asymmetries, contain risks and mitigate bubbles and thus improve economic coordination. However this boon comes at a considerable cost, whose magnitude is difficult to anticipate. What about the control of the data and the way they are aggregated and used? What about the rising complexity and lack of transparency of the system? What about the danger of its manipulation and humans becoming "digital slaves"? What about a dangerous concentration of decision power and control? What about an increase of systemic risk, if a single decision assistant system happens to outcompete all others? What about the system's vulnerability to cyber attacks?

Third, there appears to be a symbiotic, mutually reinforcing relationship between contemporary technological change and the unbundling of the value chain because of strongly falling transport costs, as it has been analysed by Richard Baldwin (2016). This involves the spreading out of "digital Taylorism", that is, scientific management worldwide, and the internationalisation of production. The platform economy and virtual firms create their own markets and rules and escape the laws and regulatory frameworks of nation states and supranational entities.

The emergence of superstar firms has a lot to do with the institutional arrangements in place. As Adam Smith insisted, the wretched spirit of monopoly is always alive, seeking to establish monopolistic conditions. The industrial and innovation policy carried out in several countries supports this spirit instead of containing it. The huge profits these firms are making allow them to expand their businesses without any borrowing. The liquid funds at their disposal in excess of what they need for growing add to the glut of savings seeking profitable investment, rising asset values and swiftly rising manager salaries and fringe benefits.

6.3 Nation state and government

Our discussion has already touched on the swift erosion of national sovereignty and governmental control in an age of globalisation-cum-rapid digitalisation. Friedrich August von Hayek (1982, p. 128) argued that "the effective limitation of power is the most important problem of social order. Government is indispensable for the formation of such an order only to protect all against coercion and violence from others." He added: "But as soon as, to achieve this, government successfully claims the monopoly of coercion and violence, it becomes also the chief threat to individual freedom."

This threat still exists and with new surveillance technologies and methods of monitoring peoples' behaviour has assumed nightmarish dimension. But is government still the "main threat" to individual freedom? There is reason to think that, apart from powerful authoritarian regimes, this is no longer the case. Given the amount of personal data available to them, rogue platform companies are able to secretly manipulate their customers in ways and to an extent never seen before in history.

Superstar firms do not only impact the labour market, they also amass huge economic and political power and therefore undermine national sovereignty: By shifting their profits to tax oases, they engender an unfair competition with traditional firms, induce a ruinous tax competition among countries and regions and erode the tax basis of nation states. In order to increase their chances to survive, traditional firms are forced to evade taxes by moving into the underground economy, which exacerbates the situation and renders the goal of balanced public budgets a more and more costly exercise. At the same time the state and public authorities face a growing number of serious tasks that cannot be met in terms of shrinking means. These tasks include: (i) the provision of a digital infrastructure that allows firms, public authorities and citizens to make the best of the new technologies; (ii) the elaboration of a regulatory framework that seeks to harvest the benefits and ward off the costs and dangers associated with the new technologies; (iii) the strengthening of a national or supranational (EU) system of innovation without paving the way to a further concentration of market power; (iv) the reform of the education system, broadly understood, with the aim of improving the fit between available and needed skills and capabilities; (v) an employment and social policy that contains the negative effects that are unavoidably associated with structural economic, social and cultural change; and (vi) the establishment of institutions capable of effectively fighting cyber criminality in all domains of life, private, political and economic.

7. Creative destruction: Who compensates the losers?

The question who benefits and who suffers from a particular economic policy or innovation has concerned economists from an early time onwards. David Ricardo set the stage when criticising the Corn Laws, which, after they had been suspended during the late eighteenth century, were reinstated again at the end of the Napoleonic Wars in 1815. The Corn Laws, he insisted, were not in the interest of society at large, as its advocates had contended: the only class that benefited were the landlords, whereas both workers and capitalists suffered from it. He wrote: "the loss is wholly on one side, and the gain wholly on the other; and if corn could by importation be procured cheaper, the loss in consequence of not importing is far greater on one side, than the gain is on the other" (Works I, p. 336; emphasis added). Hence, the effects of the Corn Laws could be compared to those of technological regress. Most importantly, its beneficiaries, landlords, could not possibly compensate the losers, workers and capitalists, because their gains in physical terms were smaller than the losses incurred by the other classes of society. Nicholas Kaldor (1939), inspired by Ricardo, took the repeal of the Corn Laws in 1846 to illustrate the compensation criterion he suggested as a solution to the problem in welfare theory that policy measures typically have gainers and losers.

Schumpeter spoke with regard to innovations aptly of processes of "creative destruction". People typically admire and cherish the successful innovator because of the creative part of his or her accomplishments. They tend to overlook the destructive part that is inseparable from it and is reflected in losses of jobs, the obsolescence of human and other types of capital, the bankruptcy of firms and the demise of entire industries. The involved cognitive distortion ought to be overcome by imputing both kinds of effects to the innovator and involving him in compensating the losers.

The question is whether this can be done ex ante, that is, at the time of an invention or the launching of an innovation. Can workers insure against unemployment and declining wages, firms against dwindling profits and assets, banks against defaults on loans? Is there a market in which agents can get insured against any risks of technological change that might reduce their income and wealth? And if there is such a market, is it perfect? In this case the innovator would offer to compensate the losers and both parties would benefit from the innovation.

As Korinek and Stiglitz (2019) emphasise, there are compelling reasons why there are no ideal risk markets in the real world. First, the problem is fundamental uncertainty rather than risk and it relates to events taking place into a distant future about which agents know very little. Second, there are the usual problems of asymmetric information, adverse selection and moral hazard that prevent the emergence of such markets. The authors conclude that compensating agents for the losses they incur as a consequence of innovations cannot be decided ex ante, but has to be done ex post. It therefore necessarily involves a redistribution of income. Redistribution programs, however, typically meet with stiff opposition on the ground that they interfere with the market and its alleged efficiency. Yet in the situation under consideration, and for the reasons given, the efficiency properties typically attributed to perfect markets cannot be invoked as an argument against a policy of income and wealth distribution.[62]

The kind of problem we are concerned with here has been analysed by John Rawls in his Theory of Justice (⟨1971⟩ 1999). He started from the premise that the future is clouded by fundamental uncertainty and no single agent is able to foretell which position he or she will assume in it. In such a situation, in which decisions have to be taken under a veil of ignorance, Rawls argued that the "Maximin principle" ought to apply. This is a justice criterion according to which the social system should be designed in such a way that the positions of those who will be worst off in it get maximised. This is possible, because the more fortunate are involved in promoting the wellbeing of the less fortunate. With regard to a system that is permanently in movement this does not mean that the worst positions today cannot get worse in the future – think of wars and epidemics. But in the case of productivity enhancing technological change the probability of this is small, provided economic policy successfully fights economic crises and unemployment. Innovations that deserve to be called that way, should, on balance, be more productive than destructive and therefore allow the innovators to compensate the losers.

A redistribution policy post factum appears also to be justified with view to the hybrid public-private character of several of the economic activities under consideration here (see Sections 5 and 6). The taxpayer's money has frequently helped to finance the development of new technologies and pave the way for new and highly successful firms – the Big Five are cases in point. It would only be fair if the taxpayer participated also in profits they make and the wealth they accumulate. There are many ways in which this could be effectuated. Otherwise the taxpayer could rightly object that while costs of innovations are getting socialised, profits are getting privatised.

Finally, if the new technologies happen to aggravate the trend towards greater inequality of income and wealth and contribute to larger unemployment or insecure jobs for significant parts of the workforce, the situation may easily threaten the foundations of democratic and liberal societies. In this context studies by Case and Deaton for the U.S. are worth mentioning. They found that overall mortality and morbidity among white non-Hispanic Americans in midlife climbed since the turn of the century through 2015[63] due to an increase in suicides, drug overdoses and drug-related diseases. The phenomenon is also known as "deaths of despair". The two authors argue that progressively worsening labour market opportunities as a result of globalisation, technological progress, structural change and an ineffective economic policy have long-term effects and cannot be reversed within a short period of time by improved earnings and jobs, or redistribution policy. The lesson they draw from their findings is that it is important to avoid cumulative disadvantages from an early time on. An inclusive approach to the absorption of technological change can be expected to reduce opposition to the new, avoid social tensions, smoothen the transition process and propel economic efficiency and productivity. And it may prevent the principle of "One person, one vote" from getting replaced by that of "One Dollar, one vote".

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Endnotes

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1 See, e.g., Steffen et al. (2018).

2 For a use of the scenario technique, see, for example, the dynamic input-output analyses in Leontief and Duchin (1986) and Kalmbach and Kurz (1992) in studying the impact of automation in production and offices in the United States and Germany, respectively.

3 See, for example, Arntz, Gregory and Zierahn (2018).

4 Kurzweil (2005).

5 According to a survey carried out by Pega, 77 percent of the global consumers interviewed use a device powered by AI, with only 33 percent actually realizing it: https://www1.pega.com/system/files/resources/2017-11/what-consumers-really-think-of-ai-infographic.pdf.

6 Lipsey et al. (2005) 133.

7 Martin (1993).

8 Lipsey and Bekar (1995).

9 Bresnahan and Trajtenberg (1995). Anticipations of these concepts in the older literature were technological changes in so-called "key" or "leading" sectors of the economy or "basic industries" (Sraffa [1960]), whose products enter directly or indirectly in the production of all industries and thus spread the novelty throughout the economic system.

10 E.g., Helpman and Trajtenberg (1998a, 1998b); Aghion and Howitt (1998); Petsas (2003); Harada (2010); Rainer and Strohmaier (2014); Cantner and Vannuccini (2017).

11 Cf. Bresnahan (2010) 764.

12 While the ENIAC (Electronic Numerical Integrator and Computer) had been invented in 1945 and was Turing-complete and digital, it was too costly and not powerful enough to be marketable and usable on a large scale.

13 Brynjolfsson et al. (2018).

14 Agrawal et al. (2018).

15 E.g., Perez (1983); Mokyr (1990); Lipsey et al. (2005).

16 Helpman and Trajtenberg (1998a,b); Aghion and Howitt (1998).

17 Cantner and Vannuccini (2012).

18 Although they are named after the Russian economist Nikolai R. Kondratieff who advocated the long cycle concept in his work (1926), he was not the first to claim the existence of long waves in economic history: The conception goes back at least to Jevons and was further substantiated by Van Gelderen (1913), who linked the upswing of the cycle to the rise of "leading sectors". See also Freeman et al. (1982) and Ayres (1990).

19 See Schumpeter (1912, 1934); for a summary account, see Kurz (2012).

20 Freeman et al. (1982).

21 Freeman et al. (1982).

22 Ayres (1990).

23 See Kurz and Salvadori (1995), especially chap.s 4 and 5.

24 See Kurz (2017a).

25 Cf. White (1968).

26 Cf. Fogel (1999) 3.

27 Ayres (1990).

28 Rosenberg and Trajtenberg (2004).

29 Ayres (1990).

30 Ayres (1990).

[31] For a summary account, see Kalmbach (2008).
[32] For a dynamic model that investigates a case of technical change that has Ricardian features and corroborates Ricardo's view, see Haas (2017).
[33] Ayres (1990).
[34] Mazzucato (2014).
[35] See e.g., Wilenius and Casti (2015).
[36] Brynjolfsson and McAfee (2014).
[37] See e.g. Graef (2011).
[38] Beernaert and Fribourg-Blanc (2017) 567.
[39] Pelka and Baldi (2017) 57.
[40] Pelka and Baldi (2017).
[41] Lewis (2018).
[42] Mazzucato (2014).
[43] Cf. EC (2010).
[44] Cf. The White House (2011).
[45] See e.g., Wübbeke et al. (2016) for a detailed description of this policy initiative.
[46] Floridi (2014).
[47] For example, Google's Director of Engineering, Ray Kurzweil, predicts that by 2029 AI will achieve human levels of intelligence.
[48] See also Hagemann (2017); Tichy (2017); Kurz (2017b).
[49] See e.g., Frey and Osborne (2017) for the USA, Arntz et al. (2016) for a selection of OECD countries or Nagl et al. (2017) for Austria.
[50] See e.g., Kurz and Salvadori (1995) chap. 6.
[51] See e.g., Vivarelli (2014) or Calvino and Virgillito (2017) for a classification.
[52] See Acemoglu and Autor (2011).
[53] See also Tichy (2017).
[54] Atkinson (2015); see also Zilian et al. (2016) for an overview of the empirical literature.
[55] See Autor et al. (2017); Guellec and Paunov (2017); Karabarbounis and Neiman (2014); Nascia and Piante (2009).
[56] Nascia and Piante (2009).
[57] See e.g., Autor et al. (2017).
[58] Guellec and Paunov (2017).
[59] See e.g., DiMaggio (2004), Van Dijk (2012); Robinson et al. (2015).
[60] See Robinson et al. (2015).
[61] See e .g., Schütz et al. (2018) for the transformation process to data capitalism and the importance of superstar firms in the digital revolution.
[62] Kenneth Arrow in the course of his life became disenchanted with general equilibrium theory, for which he had received (together with John Hicks) the Sveriges Riksbank Prize in Economics in 1972. In a flyer announcing a talk he gave at the Austrian National Bank on 22 October 2013, he stated: "A key factor in the organization of the economy is the set of beliefs that people have about each other. They change those beliefs by searching, by computing, by analysing, and when looked at properly, this gives rise to some considerable anomalies when compared with the standard theories that I and many others have developed. So in some sense, I'm finding some difficulty with work I've done in the past." In the talk he referred to Schumpeter and innovations, whose economic success (or failure) cannot be foreseen, and which may give rise to irrational exuberance, excessive speculation, herd behaviour and bubbles (as, for example, the dot.com bubble, also known as the Internet bubble, did).
[63] Case and Deaton (2017).

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Abstract

We discuss the characteristics and achievements as well as the risks and challenges of the digitalisation of the economy against the background of previous waves of technological change. Placing the argument in an historical context and reviewing how economists have assessed earlier forms of radical innovations allows us to specify what is genuinely new this time and what is a variation on a known theme. We first mention some major reasons, why it is difficult to fathom what the future will bring. We then turn to a brief account of the concepts and tools forged in order to cope with the intricate problems at hand. Then follows a history of mankind in a nutshell in terms of a sequence of Kondratieff waves. The longest section deals with some of the effects "smart" technologies can be expected to have on labour, employment and wages, on firms, profits and market forms, and on the public sector and state. With reference to Schumpeter's concept of "creative destruction" we ask who should compensate the losers in this process. An inclusive approach to this problem appears to be indispensable in the interest of a smooth absorption of the new and effective exploitation of the opportunities it offers.

Zusammenfassung

Wir diskutieren die Eigenschaften und Errungenschaften ebenso wie die Risiken und Herausforderungen der Digitalisierung der Wirtschaft vor dem Hintergrund früherer Wellen technologischen Wandels. Die Einbettung in einen historischen Kontext und die Kommentierung früherer Formen radikaler Innovationen durch Ökonomen schärft den Blick für das, was heute genuin neu ist und was nur eine Variation zu einem alten Thema. Wir beginnen mit einem Überblick über die Schwierigkeit, die Zukunft zu erschließen, gefolgt von der Vorstellung einiger wichtiger analytischer Konzepte und Instrumente. Eine kurze Geschichte der Menschheit unter Verwendung von Kondratieff-Wellen schließt sich an. Der längste Teil des Essays befasst sich mit den zu erwartenden Auswirkungen „smarter" Technologien auf Arbeit, Beschäftigung und Löhne, Firmen, Gewinne und Marktformen sowie die öffentliche Hand und den Staat. Unter Bezug auf Schumpeters Konzept der „schöpferischen Zerstörung" fragen wir, wer die Verlierer in diesem Prozess kompensiert. Ein inklusiver Ansatz ist unabdingbar im Interesse einer reibungslosen Absorption des Neuen und effektiven Nutzung seiner Chancen.

Key words: digitalisation, general purpose technologies, long waves, radical innovation, socio-economic transformation.
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