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Digital manufacturing revolutions as political projects and hypes:

evidences from the auto sector

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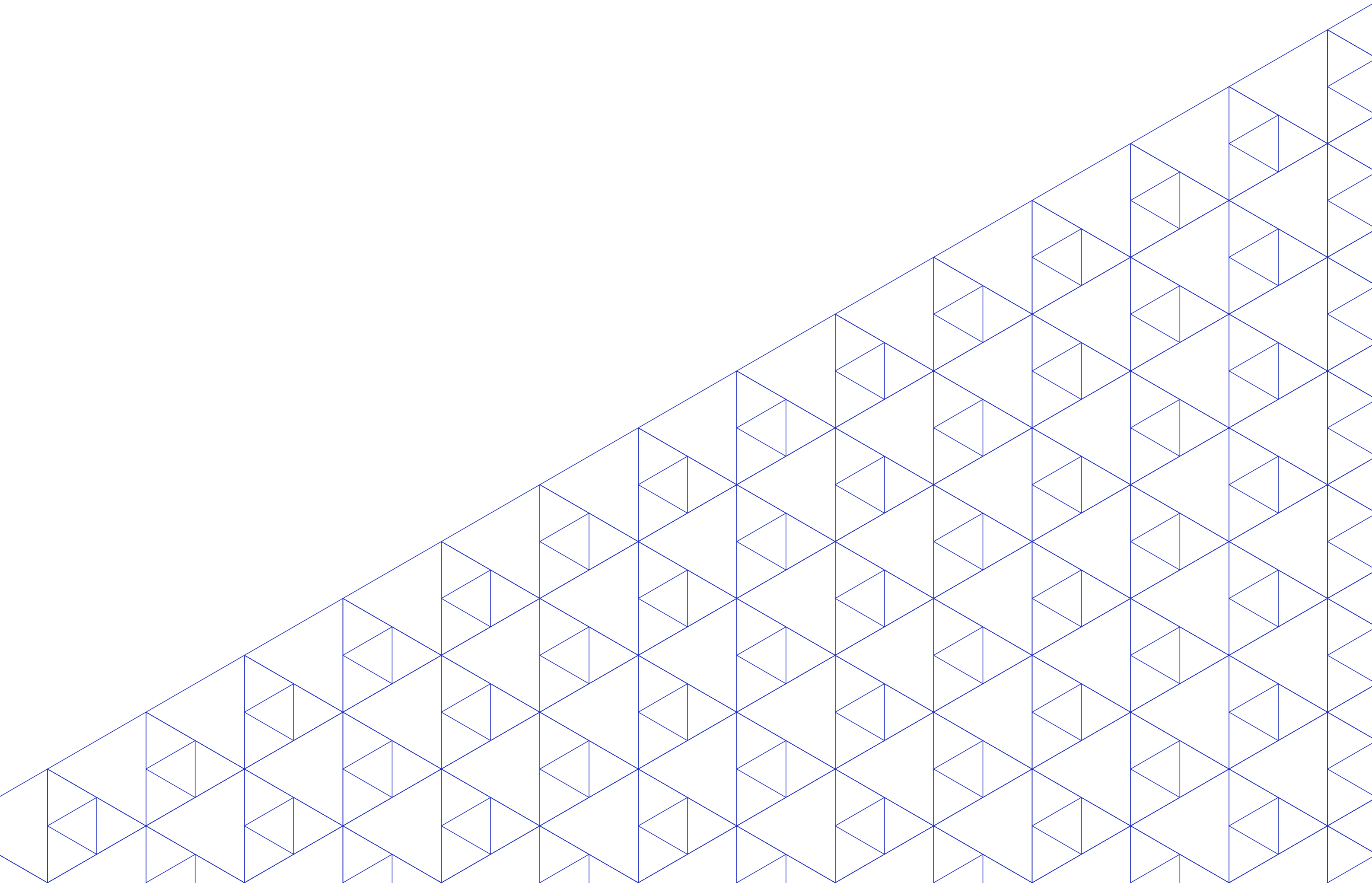

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Abstract

The article analyses the evolution of automotive manufacturing technologies and organisations and assesses the impact of “fourth industrial revolution” concepts and policies (in Germany, US and China) in particular for employment and work. While it dismisses the idea that a fourth industrial revolution is under way and that a radical break will happen in the coming years, it shows that more subtle changes are taking place on the shop-floor of automotive factories that might result in deskilling and work intensification. The article advocates for a more active role of trade unions and social partners in challenging these narratives of disruptive change and building alternative human-centred visions of the future of work.

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'Technological determinism, the view that machines make history rather than people, is not correct; it is only a cryptic, mystifying, escapist, and pacifying explanation of a reality perhaps too forbidding (and familiar) to confront directly' (Noble 1984, xiii).

Introduction

The debate about the future of global manufacturing is all about revolutionary transformations. A world where smart factories would be connected between them and with consumers through digital technologies that would allow for the production of an almost infinite variety of customised products built to order by 3D printers and intelligent co-robots. In these smart factories production, maintenance and logistics would be managed by artificial intelligences, constantly improving efficiency and quality through machine learning using the big data generated by connected objects and sensors through all the value chain. These visions of a brave new world have been promoted by consortiums of technology providers in mechanical and electric engineering sectors and in the ITC sector, mainly in Germany, United States and China, where they have also informed a new set of industrial policies that are now spreading to other countries. Under the concepts of industry 4.0 and advanced or digital manufacturing these visions have been endorsed by the main global consulting companies and they have become mainstream in media and politics. A substantial scientific literature has also promoted the idea of an imminent digital revolution, or of a "second machine age" (Brynjolfsson and McAfee 2014).

According to this new vision the automotive industry is expected to be at the forefront of the "fourth industrial revolution": first, because the automotive sector has been historically a pioneer in introducing new manufacturing technology from mass to lean production; second, because it is one of the largest and most capital-intensive industries, which concentrates alone around 40% of the world stock of operational robots but still employs a sizeable amount of unskilled and relatively well-paid workers (Sirkin, Zinser, and Rose 2015); third, because the variety and the degree of customisation of the automotive production have been constantly increasing, stretching the capability of the existing technologies to meet these demands and paving the way to a paradigm shift in manufacturing.

While these new technologies are deemed to be "disruptive", their impact is generally presented as positive for almost all the existing players: they would allow fast and increasing productivity gains; cheaper and more advanced diversified products; the elimination of hard repetitive tasks; the reshoring of manufacturing in high wages countries since the cost of work will become less a factor for international competitiveness; but also the economic and functional upgrading of supply chains in emerging countries. Against this general positive outlook, the only problem seems to concern employment, as gloomy prophesies of machine-human substitution cast a long shadow on the future of human work in automotive manufacturing. According for instance to BCG, "fewer than 8% of tasks in the U.S. transportation-equipment industry are automated, compared with a potential of 53%" (Sirkin, Zinser, and Rose 2015, 6). At the world level this potential would rise to 85% (Sirkin, Zinser, and Rose 2015, 15) and since robots are becoming "cheaper, smaller and more flexible" BCG forecasts that the rate of automation of all these tasks will increase exponentially worldwide to reach "near saturation in the late 2020s" (Sirkin, Zinser, and Rose 2015, 20). With comparable accounting methods based on experts' evaluations of the technological potential for automation in different occupational groups, Frey and Osborne (2013) come to similar conclusions, anticipating the potential loss of more than 84% of the current jobs in automotive manufacturing and up to 97% for team assemblers during the next two decades. However, the deviation of the findings (35-84%) suggests that the impact and scope of automation remains unclear. Other studies estimate that the overall share of jobs at risk of automation is around 35% in Finland (Pajarinen and Rouvinen 2014), as high as 59% in Germany (Brzeski and Burk 2015), and between 45% and 63% in Europe (Bowles 2014).

These studies focus on Western developed countries, but forecasts concerning emerging countries are not much more encouraging. A recent ILO survey of South-East Asian countries estimates that the job losses linked to future automation will range between 45% for Thailand and 70% for Vietnam by 2030 (Chang and Huynh 2016), and identifies the automotive industry as one of the sectors that will be firstly and mainly concerned by these transformations.

Despite such alarming perspectives, these forecasts are not publicly contested and translate into different scenarios and policy recommendations. Governments and firms are encouraged to promote these technologies in order to benefit from stronger productivity growth and they are expected to anticipate the related massive jobs losses by introducing or reforming lifelong training schemes that will also provide the fewer but more skilled workers who will interact with co-robots and smart technologies. Some countries are also considering the possibility of subsidizing labour costs and taxing technologies and robots (Ernst, Merola, and Samaan 2019)

As already mentioned before, during the last ten years this kind of forecasts, scenarios and policy recommendations have gained strong visibility and a diffused political consensus has been built around them. While there are softer and harder versions of this consensus depending on the timing (before or after 2030) and scope (the rate of jobs substituted by machines and AI) of the expected transformations, it is difficult to spot in political arenas many controversies and debates concerning the fundamental direction of change. As a result, even though it is not clear whether a digital revolution in manufacturing is really happening, empowered technological determinism of this kind can already produce important effects. On the one hand, it makes it difficult to contest, criticize or resist the diffusion of these new technologies, regardless of their political and social consequences or even of their effective impact on efficiency and quality. On the other hand, these visions can very well turn into self-fulfilling prophecies: as the belief in a digital revolution in manufacturing spreads, more resources are allocated to develop these technologies and more firms start to introduce them in their workplaces, reinforcing as the result the belief that a digital revolution is happening, leading to even more resources allocated and more firms implementing these technologies and substituting men with machines, and contributing as a result to decreasing the prices of new technologies through economies of scale.

In such a context to think about the future of work and employment is obviously a challenging task. As we will see more in detail below, so far the impacts of industry 4.0 and digital advanced manufacturing technologies in the automotive industry appear to be small, and there do not seem to be clear prospects for their future widespread implementation and diffusion, at least in mass production. Yet according to this powerful vision, the present state of manufacturing in the automotive sector should not matter because what we are dealing with are “disruptive” transformations that only visions of the future can make sense of (Brynjolfsson and McAfee 2014). Such a normative position leads to a paradox since the relationship between the present and the future is somehow reversed. It is not anymore the future that is understood and envisioned as the product of present evolutions, but it is the present that is shaped by visions of more or less distant futures based on the promises of digital technologies. In other words those who control these visions, orient business behaviour, policy making and workers’ expectations.

What we would like to do in this article is to reverse back this perspective and reconnect empirically grounded studies of the evolution of automotive manufacturing with the future of work, employment and manufacturing. We argue that such an approach is necessary not only to produce more realistic scenarios for stakeholders and policymakers, but even more important to bring back politics and work in the debate about the future of manufacturing.

To fulfil this agenda the article will be organised as follows. First, we will introduce the notion of “performativity” as an analytic tool to deconstruct the determinist premises of industry 4.0 and digital manufacturing revolutions concepts. This notion has been used in social sciences to analyse economic theories, managerial fashions and technology expectations from a critical perspective and will provide a theoretical framework to organise the other parts of the article. Second, we will focus on the most significant aspects of the recent history of automation in the automotive sector, starting from the 1980s and moving up to present time. We will analyse the significance but also the limits of the first wave of digitalization and automation of automotive manufacturing that has reached its peak in the 1990s. We will stress in particular the reasons why human labour and human agency still have a central place in highly standardized production environments. Third, we will analyse more in detail the three main concepts promoting the idea of a digital revolution in manufacturing: industry 4.0, advanced manufacturing and Made in China 2025. The objective is to show that these concepts are not “neutral” visions of technological progress but political projects promoted by different consortiums of technology providers supported by their respective governments in Germany, US and China. In this section we will also provide a preliminary overview of the recent transformations of automotive manufacturing by looking at the rate and degree of introduction of industry 4.0 and other related technologies in automotive factories in these countries. Finally, on the basis of the analysis developed in the previous sections of the forces at work, the dynamics in place, and the first outcomes in terms of diffusion and impact of these new technologies, we will discuss the place of politics and workers in the future of work.

1

Performativity and digital revolutions

What does confer to certain concepts, theory and future expectations the power of bringing into being new worlds as self-fulfilling prophecies? This question dates back at least to the seminal work of Karl Polanyi on the “Great transformation” of modern economies under the influence of liberal economic theories (K. Polanyi 1944). It has acquired growing attention from social scientists in recent times as the number and the importance of these phenomena have substantially increased under the form of hypes and fashions. For instance, it took almost 80 years before the first industrial revolution was called in this way by the British economic historian Arnold Toynbee, but in the case of industry 4.0 the concept has appeared before any trace of a digital revolution in manufacturing was actually visible in firms.

The question has two main dimensions: first, to understand by which means theories and concepts can shape the world; second, to identify the conditions under which this power can act. The concept of “performativity” has been developed and used in social sciences to analyse and deconstruct this type of phenomena. It has been applied to economic theories (D. A. MacKenzie, Muniesa, and Siu 2007), managerial fashions (Abrahamson and Fairchild 1999), technology expectations (Pollock and Williams 2010) and their respective capacities of world making. The concept comes from linguistics where it has been used to describe utterances that produce what they announce like, for example, "the meeting is now adjourned" or "war is declared". It has been introduced in science and technology studies (STS) to explore the role that “technological expectations” play in different forms of world making. As argued by Pollock and Williams (2010), technological expectations “are crucial to the development and shaping of new science and technology” (p. 526). They “attract attention from (financial) sponsors,” they “stimulate agenda-setting processes (both technical and political)” and they “build ‘protected spaces’” where new technologies can be developed (Geels and Smit 2000, 882). For these very reasons, technological expectations tend to be “hyperbolical” and “overly optimistic” (Borup et al. 2006, 286). In fact, very few of them manage to build worlds that comply with their forecasts and visions. A well-documented exception is the famous “Moore’s Law” according to which the microchip would keep increasing its processing power at exponential rate (Pollock and Williams 2010, 529; Van Lente 1993). But even the performativity of very successful technology expectations tend to last only a limit amount of time, producing hypes that support some development and diffusion, but ultimately fail to bring the predictions into being (Borup et al. 2006; Geels and Smit 2000). In the case of industry 4.0 and digital manufacturing revolution it is too early to precisely evaluate their respective degree of performativity. This literature highlights however some important points that we can retain for our analysis.

First, as any other technological expectations, these concepts and visions are not scientifically grounded forecasts of probable futures, but political projects that aim at shaping improbable futures. To analyse these political projects, it is therefore important to identify the consortium of actors who have built them, their objectives and strategies, as well as the role that interest groups and the state are playing in their development. This will allow not only to deconstruct the deterministic premises of these concepts, but also to understand what is really at stake behind the narrative of revolutionary change.

Second, while these concepts have certainly already gained strong visibility and political support, it is reasonable to assume that their visions of the future are “overly optimistic”. Indeed, most of the above literature agrees on the fact that technology expectations are becoming more unrealistic due both to the increasing complexity of the processes involved and the longer time horizon of the forecasts associated with them (Borup et al. 2006; Pollock and Williams 2010) – two features that are well represented in industry 4.0 and other related concepts. This means that what we are dealing with are most probably hypes. But hypes still produce important consequences: through the well know mechanisms of institutional isomorphism (DiMaggio and Powell 1983) they can work as powerful drivers for the diffusion of new technologies and managerial devices. However, the scope and outcome of these hypes crucially depends on the conditions of their reception (Abrahamson and Fairchild 1999; Pardi 2015). The literature on managerial fashions has shown in particular that the peak of the hype, after which managerial fashions fade away rapidly, is reached when their “magic properties” start to be increasingly rejected by the scientific literature (Abrahamson and Fairchild 1999, 729, 731), and when its negative consequences on firms and organizations start to be collectively denounced and resisted by professional groups, trade unions and other forms of collective organizations (Tolbert and Zucker 1999). In other terms, not only these concepts are political projects, but also their degree of performativity directly depends on the political reactions to them.

Third, the performativity of technology expectations is limited for objective reasons that can be identified and which explain why the new technology could not live up to the "overly optimistic" expectations. In our case, this is of course difficult to do since the technologies involved have just started to be implemented and their diffusion in the automotive sector is still marginal. Yet, in the current debate about the digitalisation and automation of work, some of the assumptions on which the new "digital revolution" narrative has been built have started to be challenged and contested (Paus 2018), notably by economists concerned by the forecasts of future massive destructions of jobs. D. Autor (2015) has in particular developed two convincing arguments that dismiss the current "automation anxiety".

The first argument is historical and consists in looking back at previous phases of "automation anxiety". Autor focuses on the 1950s and 1960s "Automation jobless" threat in the US that pushed the Johnson administration to create an ad-hoc Commission in ways that are very similar to the present debates about massive technological unemployment (p. 3-4). Autor argues that previous phases of "automation anxiety" proved systematically wrong, and he suggests that this could be also the case in the current configuration.

The second argument is analytical and consists in understanding the reasons why these "doom" prophecies turn out to be wrong in the past. Autor highlights two main reasons. First, automation can only substitute for certain tasks (typically the most repetitive and standardised ones) while others are still required to complete the job. When the first are automated, the latter increase in importance and value. The overall effect of this dynamic is job creation: not only because the productivity gains should raise output and therefore employment, but also because new employment is created in the tasks that are complemented by automation.

The second reason highlighted by Autor is that even relatively routinized tasks in the so-called low-skilled jobs can prove very difficult or even impossible to automate due to the M. Polany's paradox according to which "we know more than we can tell" (M. Polanyi 1966). Tacit knowledge is crucially involved in any task demanding "flexibility, judgment, and common sense—skills that we understand only tacitly" (p. 11). Two categories of tasks fall broadly under this definition: those that require "problem-solving capabilities, intuition, creativity, and persuasion" – which are associated with professional, technical and managerial professions; and those that require "situational adaptability, visual and language recognition, and in-person interactions—which we call "manual" tasks" (p. 12).

Autor argues that this paradox could also explain one of the major transformations of the employment structure in the US and other developed countries: the polarization of jobs at the high end and low end of the employment spectrum (p. 12). Increase in automation would therefore not reduce the quantity of jobs, but "it may greatly affect the quality of jobs available" (p. 9) because it leads to "the simultaneous growth of high-education, high-wage jobs at one end and low-education, low-wage jobs at the other end, both at the expense of middle-wage, middle education jobs" (p. 12). As we will see later on, there are evidences that this could be the case for some industry 4.0 technologies, in particular concerning predictive maintenance of machines and robots. However, as we will discuss in the next section on the previous wave of automation in the 1980s and 1990s, one could also argue that job polarization has been the outcome of managerial strategies aimed at re-establishing the "right to manage" in the context of struggles for the control of the shop floor rather than of technology per se.

2 Workplace automation in the automotive sector: historical patterns and current prospects

Since the introduction of mass production in the 1910s the stamping, welding and painting of the car have been progressively mechanized paving the way in the 1970s and 1980s to the automation of most of these assembly operations. By contrast final assembly where most of the variety and complexity of the assembly process converged was still manually intensive and concentrated over 60% of the total employment in the factories (MacDuffie and Pil 1997, 247). The most important efforts in terms of automation focused in the 1980s on breaking the final assembly bottleneck in order to move towards the engineers' dream of an almost unmanned factory. These efforts came in particular from carmakers that suffered in the 1970s from productivity and quality problems and saw the automation of the whole assembly process as the ultimate solution to these issues. GM and Fiat were amongst the most engaged in this process (Camuffo and Volpato 1997). These were also companies that had poor industrial relations and struggled to keep control of the shop floor (Hatzfeld et al. 2005; Berta 1998; Durand, Stewart, and Castillo 1999). In the case of Volkswagen, another company that pushed for the automation of final assembly, this was driven mainly by the engineering search for efficiency through technological "great leaps forward" (Jürgens, Fujimoto, and Shimokawa 1997, 397). But in both cases the result of these massive efforts were extremely expensive factories with high level of final assembly automation like the Fiat Cassino plant, the GM Hamtramck plant and the VW's Hall 54 in Wolfsburg, whose performances were overall disappointing due to frequent machine stops, which affected productivity and quality, and low flexibility which constrained and slowed down the introduction of new models (Fujimoto 1997, 216–17). By contrast, the Japanese factories that were leading the international comparison in terms of work productivity and quality performance at that time presented a much lower level of automation, in particular in final assembly.

According to Fujimoto, Japanese companies were pursuing a "low-cost automation" strategy: where the "high technology" strategy focused on "automation for the sake of automation regardless of its overall competitive performance", the "low-cost automation" strategy focused on overall competitiveness "...with the simplest, most reliable, and least expensive automation equipment" (Fujimoto 1997, 217). Because of the key role of teamworking in balancing the production lines, adjusting production volumes to demand, and constantly improving production processes, the optimal automation ratio of final assembly was here estimated "to be near zero" (Fujimoto 1997, 219).

During the second half of the 1980s, following the successful "transplantation" of Toyota, Honda and the other Japanese carmakers in the US (Kenney and Florida 1993), Western carmakers abandoned the "high technology" strategy and started to reorganize their factories according to the "lean production" paradigm. Paradoxically, this was also the time when the "low cost automation" strategy associated with lean production entered into crisis in Japan. What this strategy produces is a very efficient but also fragile assembly line where work is extremely hard and stressful, and in the context of the economic boom of the 1980s young Japanese did not want anymore to work in these factories (Shimizu 1999). This situation led to a second wave of automation efforts in the assembly area pushed this time by the Japanese carmakers and oriented towards improving the attractiveness of assembly operations by automating the most unattractive work stations – what Fujimoto has called the "human fitting" automation strategy (Fujimoto 1997, 219–26). As in the case of the Western experiments with higher level of final assembly automation, the results have not been very successful due to their high capital cost and limited flexibility and once the post-bubble recession started they were all abandoned. The solution to the work crisis consisted eventually in reducing the pressure of the lean organization by segmenting the lines, introducing buffers and use fixed stations for sub-assembly. This "human motivating" approach was notably introduced at the Kyushu factory of Toyota in the early 1990s and became later the norm for all the Toyota factories (Shimizu 2000). An important feature in the "human motivating" approach was to make work not only less hard, but also more interesting.

More radical approaches to enhance human motivation in car assembly were carried out in northern Europe during the 1980s and aimed at decoupling assembly work from the assembly lines, enriching tasks and extending time cycles. Exemplified by the well-known and extreme case of the Volvo Uddevalla plant (Berggren 1992), such approaches entailed a complete different automation strategy from the "human fitting" one. Automation in Uddevalla was aimed at supporting the work of a team between two and ten people (in 1990) who assembled the whole car on a fixed station. The focus was on material handling and parts picking-jobs and not on "unattractive" assembly tasks.

The Uddevalla case raised many debates. Lean production supporters argued that Uddevalla required twice as much hours of work to assemble a car than the average lean factory (Womack, Roos, and Jones 1990). Uddevalla supporters showed that it had better productivity and quality results than the other standard mass production factories of Volvo and argued that this was the right term of comparison to judge its performances (Berggren 1994; Freyssenet 1995). Eventually the debate came to a sudden end when Uddevalla was closed in 1992 following the 1991 economic crisis and a sharp decline in the sales of Volvo, even though the concept survived on a very ad-hoc basis in some Japanese factories, including some Toyota ones (Nohara 1998).

The second part of the 1990s saw the abandon by all the carmakers of both the "high technology" and the radical "human motivating" automation strategies and a general convergence towards the "low cost" and moderate "human fitting and motivating" automation strategies associated with lean production. As a result, at the end of the decade the rate of automation in assembly had not progressed significantly by comparison with the late 1980s, even though more flexible robots had been introduced in the body and paint shops (MacDuffie and Pil 1997). At this time, forecasts anticipated for the next decades a growing diffusion of automation, including in final assembly, as the technologies available would become cheaper, more flexible and integrated with computer based communication systems (Hsieh, Schmahls, and Seliger 1997, 36). The year 2000s and 2010s have not confirmed these forecasts as the stocks of industrial and assembly robots in the automotive sector have tended to stagnate (see also figures 1 and 2 below) and the average rate of automation in global automotive factories has not increased or has even decreased in some cases, in particular in final assembly[1]. Several connected factors account for this evolution.

A first factor is the supply of labour. Following the collapse of Soviet Union, the entry of China in the WTO and the creation and extension of free trade zones in all the major economic regions, hundreds of millions of workers have been added to the world supply of workforce. As a result, the availability, cost and willingness to work of unskilled and skilled workers have ceased to be a problem for the automotive industry, at least for the time being. Rather than trying to pursue automation, carmakers have structured regional value chains and shifted production to low-wages countries in order to reduce their costs. The rapid growth of production for local markets in the BRICs as well as the need to upgrade factories in low-cost countries has had a mixed impact in terms of automation: on the one hand, the need to ramp-up production and improve quality has led to the creation of more capital intensive and automated factories than in the past (Jürgens and Krzywdzinski 2016); on the other hand, the development of low-cost products in these countries has also permitted the creation of modern factories with very low level of automation (Midler, Jullien, and Lung 2017).

A second factor is related to one of the precondition identified by Shimokawa et al. (1997) for the further diffusion of automation: the reduction of product variations in order to improve the design for automation (p. 9). The 2000s and 2010s have rather seen a constant increase in product variations pushed by direct competition in all the main markets and the rapid introduction of new products and technologies (Jullien and Pardi 2013). If the development of modular global platform has allowed to increase the number of common parts between product variations, the variety and complexity of the assembly process, and in particular of final assembly has constantly increased reinforcing the role of skilled experienced line-workers in the organization and optimization of the production flow (Jürgens and Krzywdzinski 2016; Pardi 2017). Under these conditions low-cost automation strategies, in particular in final assembly, should prevail.

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[1] This observation is based on several and regular factory visits and was confirmed by recent presentations by T. Fujimoto, concerning Toyota and other Japanese car makers, and U. Jürgens concerning Volkswagen : http://gerpisa.org/node/3828

A third factor is more recent and is related to the greening and digitalization of the car. The on-going shift towards electro-mobility on the one hand, and the movement towards connected and autonomous cars on the other hand, are absorbing very substantial amount of capital investments by automotive firms, to which one should add the important cost of "cleaning" internal combustion engines after the "dieselgate" and the tightening up of the homologation rules (Klebaner 2018). These trends have several implications for the automation strategies of carmakers: they reduce the capital available for expensive high-technology solutions; they increases the uncertainty concerning the nature of the future products and the conditions of their production; and they reinforce, as a result, the need for low-cost flexibility in the manufacturing organization.

While factory 4.0 and other related concepts of advanced manufacturing are now clearly pushing for a revival of high-technology automation strategies, the two main drivers that have spurred previous automation waves in the automotive sector in the 1980s and 1990s appear to be absent: neither the productivity and quality problems that affected Western carmakers in the 1980s, nor the labour shortage and workers' discontent that affected Japanese carmakers in the early 1990s are present today[2]. What is again present and diffused by the "industry 4.0" vision is the drive for automation for the sake of automation. As in the 1980s, "Technology- oriented notions, such as *the higher the automation ratio, the better, the more intelligent the robots, the better* or *the closer to unmanned operations, the better,* tend to be taken for granted, regardless of their competitive consequences" (Fujimoto 1997, 215). The question is whether this ideological oriented drive will be enough to spur a new wave of automation in the automotive sector – the disruption revolutionary hypothesis –, and if it is not, what other consequences it might have on the organization of production and work from a path-dependent evolutionary perspective.

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[2] One could argue that there are fears of labour shortage in Germany and that the cost of work in the automotive sector in China has grown steadily during the last years, but there is no much comparison with the structural crises of the 1980s.

3

Manufacturing revolution concepts as political projects

The years 2000s have been marked by declining contribution of manufacturing to GDP, historically low levels of investment in industrial equipment, and deterioration in the trade balance of manufacturing goods in almost all mature economies. These underlying negative trends have been exacerbated by the impact of the 2008-2009 crisis, triggering as a result the reactivation of voluntarist industrial policies at national and supranational level[3]. By contrast, in emerging countries, notably in the BRIC and in particular in China, the weight of manufacturing in GDP growth and the levels of industrial investments have significantly increased before the crisis and remained exceptionally high after it.

This is the context that sees the emergence of the industry 4.0 and advanced manufacturing platforms and projects in Germany and the US, followed by Made in China 2025. The section aims at characterizing these three initiatives with a special focus on their implications for the automotive sector.

Germany: Industrie 4.0

The German concept of Industrie 4.0 goes back to work in the context of the German government's high-tech strategy. The German government passed its first high-tech strategy in 2006, which was further developed in subsequent years. The Ministry of Education and Research was commissioned with the supervision of this process and was advised by the specially-founded "Research Union Business and Science" between 2006 and 2013[4].

Within the Research Union, a group of scientists and business stakeholders were responsible for developing the "Industry 4.0" concept. Representatives of the IT industry (Henning Kagermann, President of the Acatech, and former CEO of SAP, Wolfgang Wahlster, President of the German Research Center for Artificial Intelligence, and Johannes Helbig, former board member of the Deutsche Post) played a central role. In 2013, this group issued the "Implementation Recommendations Industry 4.0" (Kagermann, Wahlster, and Helbig 2013), which became the basis for further activities. In the same year, the "Platform Industrie 4.0" was founded by the three industry associations VDMA (mechanical engineering), Bitkom (IT) and ZVEI (electrical engineering). However, the associations were unable to agree on their role and the contents of the cooperation. For this reason, in 2014, the platform Industrie 4.0 has been redesigned and placed under political leadership of the German government. The main task of the platform is to develop technological standards and reference models and to advise the German government in technology policy.

From a policy perspective, Industry 4.0 is a campaign to mobilize significant public funding and private investment for technological modernization and innovation (Pfeiffer 2017). An important motivation here is the perception that Germany is strong in manufacturing, but in the field of information technologies threatens to fall behind the US, but also countries like China. The core idea of Industry 4.0 is to develop a global competitive advantage from the combination of manufacturing expertise and IT.

While the overall vision of Industrie 4.0 is to develop the "Smart Factory" based on self-organized cyber-physical systems – a concept including a very high level of decentralized self regulation of the technology –, in practice Industrie 4.0 mainly describes a bundle of technologies with different potential

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[3] The European Commission for example has set a target for 2020 of 20% contribution of manufacturing to EU GDP (from 15,5% in 2012).

[4] The members of the research union include Fraunhofer institutes, representatives of other research institutions, the Acatech (German Academy of Engineering Sciences) as well as a broad mixture of companies: Boehringer, BASF, Oetker, EADS, Telekom, Deutsche Post, IMC AG (E-learning), Giesecke (safety systems), Deutsche Bahn, Daimler, Wittenstein, Siemens, Pilz Automation

consequences. The basic technology is the Internet of Things, which establishes a network of machines, materials, components, and also workers communicating with each other. In addition to this basic technology, Industrie 4.0 includes a number of further developments:

- Efforts to integrate the often fragmented IT infrastructures in companies, to collect process-related data systematically and use new techniques to provide real-time data analysis for process control and process optimization;
- Introduction of so-called assistance systems i.e., systems running on devices like tablets, data glasses, smart watches, smart gloves and other, providing information to workers, but also allowing for tighter control of work in manufacturing processes; and finally
- New approaches to automation of manual operations.

Further technological developments such as 3D printing or the use of artificial intelligence have until now been of niche character in manufacturing and will not be analysed further here. Where 3D printing is introduced in the automotive industry, it is mainly used for the production of individual spare parts, and its deployment in mass production is in a very early stage and it is not clear if it will be possible in the middle term. Applications of artificial intelligence are so far highly specialized (e.g., image recognition systems used for quality control). More sophisticated applications of artificial intelligence, for instance, for the directing of automated guided vehicles in internal logistics are under development in laboratories but not yet deployed at a large scale in the factories.

Integration of IT infrastructures and new forms of process control and optimization

One of the key promises of the Industrie 4.0 discussion is new possibilities for data-based optimization of production processes. By integrating all levels of IT systems from machine control to manufacturing execution systems (MES) and to enterprise resource planning (ERP), Industrie 4.0 aims at providing comprehensive process transparency to management. The study of Nyhuis et al. (2017; Schlick et al. 2014; Meyer et al. 2018) about the impact of Industrie 4.0 on production planning emphasizes optimization potentials, for example, in (a) production program planning through the use of big-data evaluations of search engine data and other indicators of future demand, (b) order management by accelerating the flow of information on the progress of order processing, and (c) manufacturing control by providing more accurate and quicker data on machine utilization, order backlog and breakdowns.

In particular, the new approaches to order management and production control could have an impact on work areas traditionally dominated by skilled work. A prime example is maintenance work, a domain of skilled workers. For a long time now, companies have tried to structure and rationalize work processes in maintenance. In particular the introduction of Total Productive Maintenance (TPM) concepts as an element of lean production has provided a boost to change. A part of the TPM concepts is data-based planning of maintenance work in order to avoid machine downtime (Wiremann 1991). The “Smart Maintenance” approaches discussed in the context of Industrie 4.0 put this approach on qualitatively new level (Acatech 2015). The diffusion of the Internet of Things and the integration of IT systems in companies means that there is much more process data available and that this data is available nearly in real time. In maintenance departments, this leads to the growing importance of data analysis competences and the understanding of IT systems and processes (Güntner et al. 2015) emphasize that the maintenance profession moves away from the image of the “machine whisperer” and into a profession of data analysts. This trend is accompanied by shifts in the employment structure in maintenance. On the one hand, the higher level of transparency of the production processes and the data-based control of the maintenance work allows a further allocation of maintenance tasks to production workers. First studies report the use of assistance systems to shift simpler maintenance tasks to production (Ullrich et al. 2018; Löhrer et al. 2018): wearable assistance systems can indicate for instance when and in what order a given part of the device should be inspected by the worker; when needed they can also connect an expert to the workplace in order to provide instructions on how to repair the machine. On the other hand, the “Smart Maintenance” concept recommends the centralization of process monitoring and machinery-related problem-solving processes (Acatech 2015). In the new maintenance centers, engineers and data analysts control the operation of the machinery and plan the maintenance activities. The responsibility of maintenance workers is reduced to carrying out the instructions of this control center – which means lower skill requirements.

Developments like the “Smart Maintenance” concepts are currently in their very beginning. They show, however, a possible future in which digitalization reduced the need for skilled production work and creates highly polarized employment structures in factories consisting of engineers and data analysts on the one and unskilled workers on the other hand.

Introduction of assistance systems

The systematic introduction of digital assistance systems on the shopfloor is one of the core elements of Industrie 4.0. Assistance systems are using existing IT infrastructures and knowledge data bases in order to provide information to workers. Assistance systems can be run on a number of different devices. In assembly areas, assistance systems often run on computer screens; they visualize each step of the work processes, provide problem-solving help if needed, and can be also used to control the work process, for instance, by asking the workers to confirm each finished operation. In logistics, the newest generation of assistance systems is running on data glasses. There are also assistance systems using devices like “smart” gloves. These gloves are equipped with RFID chips, location and motion trackers, and light signals. They can be fed, for instance, with information about the right sequence of movements or parts to pick, and they show a warning light if the worker does not conduct the operation to standard.

Assistance systems are expected to help companies to quickly integrate new employees into the production process without disturbing the processes themselves. This is seen as an answer to problems related to integrating new groups (for instance, immigrants) and increasing staff turnover.

Automotive OEMs and suppliers are experimenting with a large number of projects introducing assistance systems, with intralogistics being a particularly frequent field of application. So-called pick-by-light and pick-by-voice assistance systems have been used here for a long time. These systems shown the workers the items to be picked by means of a light signal or a computer-generated voice. Now, companies have begun to test so-called pick-by-vision concepts that significantly increase the transparency of the picking process. In these approaches, the logistics workers carry data glasses, which are connected to the order management system. The order management system provides the information about which products are needed, where they are to be found in the warehouse, and in what order they need to be fetched. All information and instructions are displayed step by step on the data glasses. The built-in camera or body-worn RFID (Radio Frequency Identification) chips confirm that the right products have been picked up. In addition, a precise localization of the employees is possible.

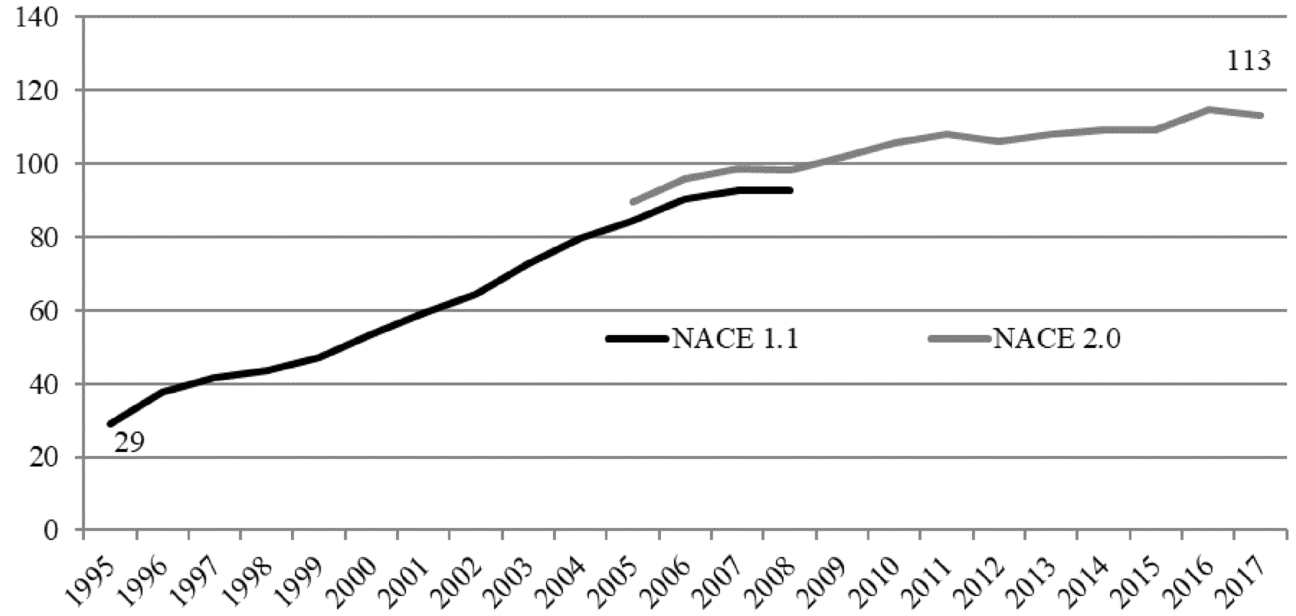
The use of such assistance systems could certainly facilitate the execution of work. For semi-skilled workers, working under high time pressure and with high quality and safety requirements can mean considerable stress that can be absorbed by digital assistance systems (Kuhlmann, Splett, and Wiegrefe 2018). Workers can now perform complex and ad-hoc tasks without fearing of making mistakes, by following real-time instructions. Furthermore, better quality procedures and standards should improve health and safety for employees. There are, however, also problematic consequences. It is unclear how the use of digital assistance systems will affect learning processes on the shop floor in the long term (Butollo et al. 2019). Negative effects can arise through the reduction of possibilities of experiential learning. The use of digital assistance systems reduces the importance of employees' own perception and their own experience, which are central to learning. Assistance systems also allow to collect data about employees – the regulation of their use will become a major issue for collective bargaining.

New approaches to automation

It has already become clear that automation in the classical sense is not at the core of Industrie 4.0 concepts. During the last years, at least in European high-wage locations of the automotive industry, there has not yet been a great boost in the field of automation. This is not least because the production at these locations is already characterized by a very high level of automation. In the case of car makers, possibilities to automate the body shop and the paint shop have been nearly exhausted; the only area strongly dominated by manual work remains the final assembly. In the German automotive supplier industry, about 54% of the companies report strongly or predominantly automated production; in 36% of the firms the production is characterized as mixed, i.e. it consists of automated and predominantly manual areas; only 10% of firms still have predominantly manual production (Krzywdzinski, Jürgens, and Pfeiffer 2016).

The following figure shows that the development of automation in the German automotive industry is a gradual, long-term process. This is illustrated here by the example of industrial robots – whereby it should be noted that robots are only one form of process automation. In recent years, the growth of robot intensity in the automotive industry has slowed down even - at least compared to the 1990s, where a much faster increase in automation was observed. This might be due to the fact that the focus of industrial robots is primarily in the body shop, where automation levels of over 90% already prevail.

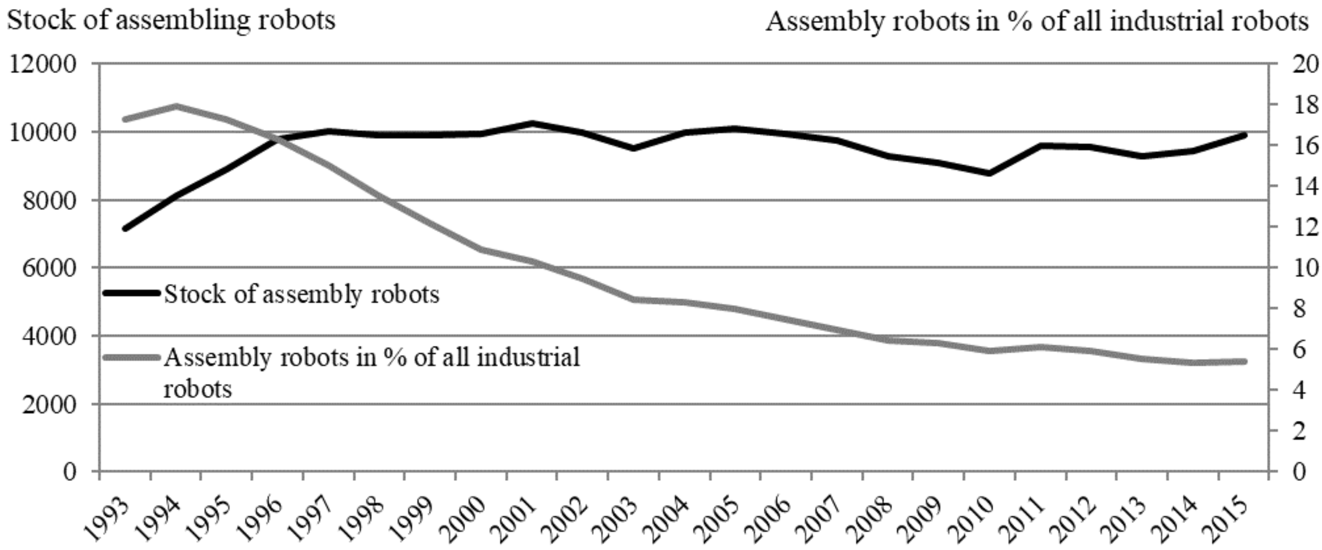
▶ **Figure 1: Stock of industrial robots per thousand employees in the German automotive industry, 1995-2015**



Source: Eurostat sbs_na_2a_dfdn and sbs_na_ind_r2; International Federation of Robotics, World Robotics 1.1.14. NACE corresponds to the sector codes used by Eurostat that has changed the classification in 2008 from NACE 1.1 to NACE 2 (here it refers to the number of employees in the German automotive industry).

Today, manual work still prevails in assembly areas of OEM and supplier plants. An important innovation in the context of Industrie 4.0 aiming at automating assembly tasks are the so-called “collaborative” robots (cobots), which can be used flexibly and whose price has dropped dramatically in recent years. Although there are a number of pilot projects related to the introduction of cobots in the plants of German car manufacturers, these projects have hitherto focused on just a few areas of activity – a huge boost in assembly automation has not yet been recorded. In the current fields of application, cobots perform particularly repetitive or ergonomically unfavourable tasks and represent therefore rather an improvement of working conditions than a systematic threat to employment. In many assembly areas, however, the use of cobots is not possible due to the spatial conditions, the variety of parts and variants as well as the volatility of the manufacturing process. As the next figure shows, there has been no increase in the number of assembly robots in Germany since the 1990s, and the proportion of assembly robots in the total inventory of industrial robots is falling.

▶ Figure 2: Assembly robots in Germany, 1993-2015



Source: International Federation of Robotics, World Robotics 1.1.14.

United States: Advanced manufacturing initiative

The concept of “advanced manufacturing” has been developed by the US Federal Government as a way to revitalize the manufacturing sector, and in particular the high-tech industries after the 2009 financial crisis. Its origin can be traced back to the US Department of Commerce’ report “Manufacturing in America” of 2004, which already highlighted the weakening of the manufacturing base for high-tech products, in particular computers and electronics, semiconductors, and electrical equipment (p. 20). The report was published in the aftermath of the 2001 recession triggered by the burst of the dot.com bubble and translated a declining confidence in the capacity of digital based services to replace manufacturing as the long-term growth engine of US economy. The report also stressed the importance of a strong manufacturing base in order to maintain US global leadership in new technologies, and as a key provider of good jobs (U.S. DoC 2004).

However, it was only after the 2009 “great recession” that the federal government really activated this industrial policy. A key move was the decision to rescue both GM and Chrysler from bankruptcy triggering the restructuring of the “Big Three” in order to restore their competitiveness by reducing capacity and labour costs. The two main arguments here were to protect well-paid jobs[5] and an industry with strong back-links, which is also a main contributor to R&D spending. Yet the main focus of this new policy was not in manufacturing industries per se, but in the development of new key technologies. As highlighted by the President’s Council of Advisors on Science and Technology (PCAST 2011), the US has become since 2001 a net importer of high-technologies goods with a deficit of 81$ billions in 2010 while the US share of the global market of exports from high-technology industries declined from around 20% in the late 1990s to about 11% in 2008 (p. 3-4). In order to counter this loss of leadership in high technologies manufacturing, the PCAST report advised the Obama administration to launch the Advanced Manufacturing Initiative (AMI). The report argued that “The Nation’s long-term ability to innovate and compete in the global economy” depended on the revitalization of the manufacturing sector. It also emphasized that “a strong advanced manufacturing sector” was “essential to national security” (p. 14). The AMI was launched in 2011 and led in 2012 to the creation of the Advanced Manufacturing Partnership (AMP) with an initial federal budget of around $500 millions.

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[5] According to the Obama’s administration « Framework for revitalizing American Manufacturing » (2009) the manufacturing sector averages more than $32 per hour, which is 22 percent higher than average compensation in service industries (p. 7).

The AMP appears from the start as a quite typical instrument of US industrial policy. On the one hand, it is supposed to address the risks of market failures in the development of new technologies justifying therefore the intervention of the State in terms that remain compatible with the laissez-faire principles historically endorsed by the US administrations. On the other hand, by putting national security at the forefront of the innovation agenda, it builds on the long-term commitment of the US administrations to the industrial-military complex and the nation innovation system built around it (Noble 1984; O'Sullivan et al. 2013; Daudt and Willcox 2016).

The main initiative taken by the AMP has been the creation of a National Network for Manufacturing Innovation (NNMI), based on regional research institutes: the Innovative Manufacturing Institutes (IMI). An initial federal budget of $1 billion was given in 2012 to finance the first 15 IMI, and a further $1.9 billion has been released in 2016 to reach 45 IMI by 2025. These funds are managed by two government agencies directly linked to the scientific military complex: the DARPA (Defense Advanced Research Projects Agency) and the NIST (National Institute of Standards and Technology). Each IMI is specialized on some key technologies and operates as a public-private partnership. While the IMI take inspiration from the German Fraunhofer Institutes, the focus is different by comparison with the Industrie 4.0 platform. Of the first five institutes created between 2012 and 2014, three are dedicated to new materials and are placed directly under the control of the Department of Defense (DoD), and the other two work on new generations of power electronics and are managed by the Department of Energy (DoE). To date (August 2018), 15 IMI have been created and 8 of them focus on new materials (such as functional fabrics, biomaterials, 3D printing, composite materials and lightweight materials), while only two are specialized on robotics, artificial intelligence and digital manufacturing.

Overall, the DoD concentrates half of the total federal spending on R&D (Daudt and Willcox 2016). Also, all the major companies involved in the AMP, such as General Electric, Lockheed Martin, Boeing, Raytheon, IBM, Honeywell, Alcoa, John Deere, ABB and DuPont are American and historically connected with the industrial-military complex and operate in the defense and aerospace sectors.

While the long-term purpose of the AMP is to foster the "birth and growth of major new industries", for the time being its impact on the shop-floor seems very limited, and concentrated in relative small scale aerospace production.

The Industrial Internet Consortium: the private answer to industry 4.0

The US equivalent of the industry 4.0 platform is the Industrial Internet Consortium, which is a private driven initiative that aims at competing with industry 4.0 in defining the interoperability standards of IoT (references architectures). The IIC has been founded by General Electric and IMB in 2014 and its membership has now grown to over 300 firms.

The IIC has developed in cooperation with the IEEE standards association the Internet Reference Architecture (IIRA) that stands as the main alternative to the Reference Architectural Model Industrie 4.0 (RAMI 4.0). Both are general frameworks to build interoperability standards for IoT. Starting from 2015 the IIC and Industrie 4.0 platform have begun to cooperate and representatives of Bosh and SAP, two of the most active German players in the Industrie 4.0 platform, now sit in the IIC steering committee. While the effective creation of interoperability standards for IoT appears to be in its infancy (Lu, Morris, and Frechette 2016), the purpose of these two consortiums is to create the conditions for the diffusion of industrial IoT and to control the standards that will make this possible.

In the case of Germany, software (SAP), IT and dominant mechanical engineering firms (Bosch, Siemens, etc.) successfully lobbied the central Government and obtained funding and political support for the development of the Industry 4.0 platform, which explain why the smart factory is now centrally integrated in the German industrial policy and benefits from a generalized involvement of the nation innovation system. In the US, this is much less the case. As highlighted above, public funding for innovation policy is essentially managed by the DoD, captured by the aerospace industry and channelled towards the traditional industrial scientific complex where smart factories and related digital manufacturing technologies have so far attracted relatively little attention.

Different reasons can account for the marginal place of digital manufacturing in the advanced manufacturing framework. A major drawback for the experimentation and the diffusion of smart and cloud manufacturing in the Defense sector is the vulnerability of these technologies to cyber-security threats

(Lu, Morris, and Frechette 2016). The use of IAs for Defense manufacturing and military applications is also very problematic, since the most advanced algorithms based on neural networks and deep learning are not accountable for the decisions they make and cannot explain them ex-post – which is unacceptable in the military chain of commands. More generally, the least emphasis on smart factories in the US can be also explained by the fact that contrary to Germany, the availability and cost of skilled and unskilled workers for manufacturing does not seem to be an issue. Hourly wages in manufacturing stagnated during the 2000s and have declined significantly after the 2009 crisis. According for instance to Sirkin et al. (2014) the US has become during this period one of most attractive locations for manufacturing worldwide due to their "moderate wage growth, sustained productivity gains, stable exchange rates, and energy cost advantages" (p. 5), a trend that has been particularly strong in the automotive sector where average real hourly wages have drop by 13% between 2004 and 2015 (Dziczek 2016).

Impact on the automotive sector

The US automotive sector is not prominent in the Advanced Manufacturing Platform: initially only Ford was involved, joined later by GM, and the strong focus on new high-tech materials and additive manufacturing is a clear evidence of the little weight of auto producers in the platform, since these technologies have no realistic applications in mass production. The same can be said about the Internet Industrial Consortium, where just few automotive suppliers from the electric and electronic sectors are represented. As expected, the impact of both these initiatives on the shop-floor of automotive companies appears so far to be almost non-existent, with a couple of minor exceptions in recent transplants of some German premium carmakers where co-robots have been experimented on ad-hoc basis[6].

The US automotive sector has been under restructuring since at least the years 2000, and this process has been dramatically amplified by the impact of the 2008 crisis and the bailout of GM and Chrysler. Following the closure of 13 factories and the loss of 128 000 jobs, the Big Three have drastically reduced their capacity and restored their cost competitiveness (Klier and Rubenstein 2012).

The bailout, followed by the fast rebound of the US market for new cars, has also provided the Big Three with the financial opportunity of modernizing their remaining factories. But rather than pushing new industry 4.0 technologies, the focus has been on replacing existing machines with more sophisticated ones in order to increase quality and flexibility. Overall, while the amount of investments in new machines has been important, automation rates have not increased (Dincer 2016). BLS data shows that since the 2000s labour productivity has increased significantly in the US automotive industry, but mainly pushed by new work rules and work intensification, while the contribution of capital investments to total factors productivity has been much less important.

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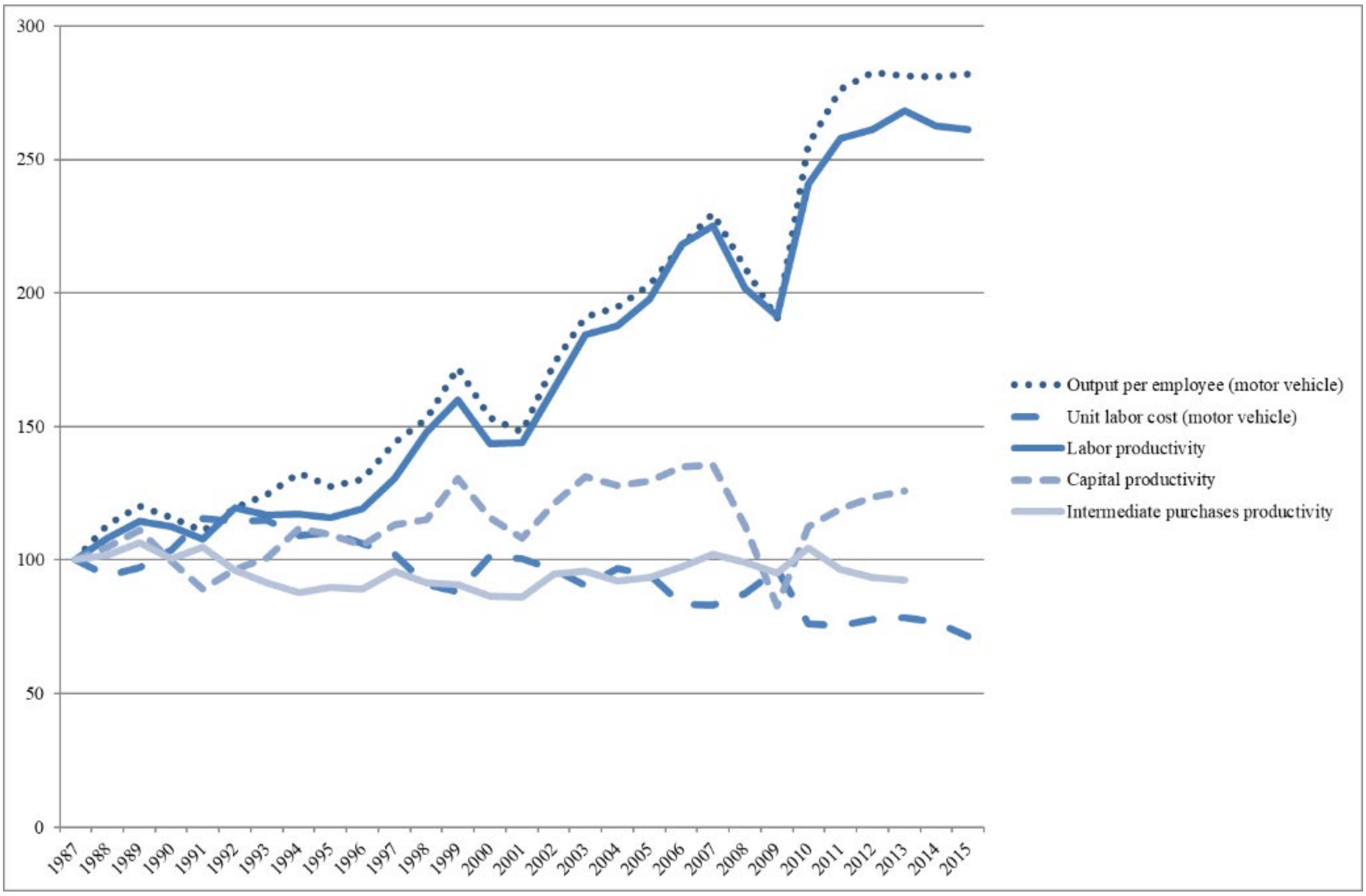
[6] In the Spartanburg BMW plant in South Carolina

Figure 3: Productivity by factor in the US car industry (1987-2015, base 100-1987)



Source: BLS.

These trends are backed up by evidence from the shop-floor. Analysing the introduction of new machines in GM Tonawanda Powertrain plant, Evren Dincer has found little impact on overall headcount. He highlights however more subtle changes linked to the elimination of the lines of demarcation for skill trades, the introduction of a multi-skilled teams approach to maintenance, the breaking up of well-established work rules and the reorganization of the training system for skilled tradespersons (Dincer 2016). If these changes are important, because they weaken the bargaining power of one of the last union strongholds in the shop-floor of the Big Three, they do not represent a departure from the restructuring logic already at play since the early 2000s. The long-term objective has been to bring down labour standards and work rules in the unionized plants of the Big Three in order to compete with non-unionized plants established by the Japanese carmakers in the Southern states where labour costs are significantly lower and labour flexibility much higher (Klier and Rubenstein 2013; Freyssenet and Jetin 2011). The lean production paradigm embodied by the transplants and based on low-cost automation, just-in-time supply chain, high work intensity and extensive use of temporary workers (Lepadatu and Janoski 2018) remains therefore at the core of all the current transformations of the North American automotive industry.

China: Made in China 2025

“Made in China 2025” (MiC 2025) appears to be the most ambitious project in the global arena to develop intelligent manufacturing. The program is a coordinated effort between government at all levels, research institutions and industry to create an advanced industrial base in ten key emerging industries. It is a centrepiece of China’s strategy of “innovation-driven development” that has been promoted since 2013 to accelerate the economic rebalancing from export-led to domestic-market-based growth (Lüthje and McNally 2015).

MiC 2025 assembles a broad spectrum of industrial actors. The concept does not bet on creating national champions from restructured state-owned enterprises - a strategy that had failed in industries such as automotive, telecommunications equipment and others. It gives a strong role to China's new rising multinationals in mid- and high-technologies such as solar systems, wind turbines, LED, household appliances or, most prominently, in telecommunications and advanced internet services. MiC 2025, therefore, reflects the increased importance of large non-state-owned enterprises, such as Huawei, Haier or BYD, as drivers of innovation and marks a substantial change in economic power relations in China.

Germany's Industry 4.0 strategy serves as the main reference point and model. However, MiC 2025 is not merely a program to promote robots and factory automation. It rather aims at the development of entire new industrial sectors and thereby reflects a strong orientation on value chains. As president Xi Jinping has made clear in several speeches, the ultimate goal is to build global production networks under Chinese leadership[7].

The focus of public policy discussions in China has in particular shifted from visions of the digital factory without workers to the development of critical infrastructure and advanced data networks and platforms, i.e. artificial intelligence, cloud computing and the "industrial internet". China's accelerated efforts in this field are part of a massive global rush to develop data platforms for manufacturing, mostly known as "industrial internet" or "internet of things". Those are basically operating systems for industrial equipment with apps to connect machines, data centres and control devices in factories, shipyards or construction sites, similar to Android, Apple iOS or other platforms for consumer smartphones. In China currently about 25 such platforms are under development, and the major players are the Chinese giants of Internet and telecommunication technologies such as Ali Baba, Tencent and Huawei, but also large industrial firms such as Sany, Haier and Foxconn.

However MiC 2025 suffers from the diverging, often contradicting dynamics between top-down and bottom-up policies, which have been described as typical for China's emerging capitalism and its regulation (McNally 2014). Provincial and local governments provide a large proportion of the resources, but have to compete for research projects and recognition from central government authorities at the same time. Strategic goals are translated into quantitative targets under the five-year plan, which are often unrealistic and difficult to meet. Over expansion and wasteful competition are the consequence. China now has more than 40 industrial parks specialised in production of industrial robots and almost nearly 2000 suppliers of robotics and components, but only few of them are competitive (Wübbeke et al. 2016).

Catching up or forging ahead? Automation at the shop-floor[8]

How does China's push for digital manufacturing play out at the shop floor? The present picture is highly differentiated among industries and companies at various levels of value chains. These differences reflect the segmented nature of industrial upgrading and innovation, which is characteristic for China's emerging variety of capitalism.

Large state-owned enterprises and joint ventures often already have highly automated manufacturing operations. Most car factories in China, for example, feature state-of-the art production technologies and work schemes that were imported with the booming of the auto industry during the last decade. Workers in core factories are relatively well paid and trained, but work pressure has often become intense and automakers heavily use temporary workers to keep wage costs down. Given the high level of automation, there is not much incentive to introduce new models of digital manufacturing and innovation in production and supply chains.

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[7] Xi Jinping (2016), Zai sheng bu ji zhuyao lingdao ganbu xuexi guanche dang de shiba jie wu zhongquanhui jingshen zhuanti yantao banshang de jianghua (Speech at leading provincial cadres studies meeting to promote the spirit of the 5th central committee meeting of the 18th party congress). Beijing: Xinhua.

[8] The following summarizes results from our ongoing field study program under the Volkswagen Endowed Chair Industrial Relations and Social Development at Sun Yat-sen University. To date, roughly thirty field studies have been conducted, most of them in the Pearl-River Delta. For a systematic explanation see Butollo & Luethje (2017).

Large, mostly private-owned brand-name firms and multinationals have successfully grown with product innovations adaptive to the domestic market. But their manufacturing has been relatively simple and labour -intensive, employing large numbers of low-paid migrant workers. Among these firms incentives to modernise manufacturing and supply chains are high, a number of them have developed national pilot factories for digital manufacturing under MiC 2025. Some companies have also been involved in high-profile acquisitions of foreign technology companies, such as Midea's takeover of the German robotics firm Kuka.

Among the vast *labour-intensive assembly industries* - still the backbone of China's exporting economy - incentives for manufacturing modernisation mainly result from rising minimum wages, regional labour shortages and increased quality demands from customers. Many small and medium-sized firms have started to employ digital automation equipment and simple, relatively cheap robots, mostly provided by Chinese equipment makers and heavily subsidised by local governments. Such companies typically work at the bottom of supply chains for global or Chinese brand-name firms and need quick return on investment under continuing price pressures.

Against this background, much of the recent automation activities in China's factories can be characterized as "catching up" with international standards of manufacturing organization, rather than "forging ahead". There has been a surge in computerized manufacturing data control systems, but this kind of digitalization remains far from intelligent manufacturing based on flexible robots, artificial intelligence and big data networks. Most automation technologies are at the stage of "industry 2.0 or 3.0, but not 4.0", as Midea-CEO Fang Hongbo explained in recent media interviews[9].

Digital manufacturing in the car industry

The car industry as a whole is not a strategic sector under Made in China 2025. Only New Energy Vehicles (NEV) is among the ten emerging industries of this program. In this area China can hope to leapfrog the incumbent carmakers from developed industrial countries and to build indigenous brands and innovation, a goal that has not been achieved in the traditional car industry dominated by Chinese-foreign joint ventures. Some carmakers, from Germany especially, take part in highly publicized promotions of German-Chinese collaboration in industry 4.0. But in reality, industry 4.0-type manufacturing schemes are not significant at the shop-floor. The prevailing tendency of rationalization is to solidify and optimize methods of lean production and to improve efficiency under the conditions of China's "new normal"[10] with much lower growth rates than in the previous two decades (Lüthje and Tian 2015).

The situation reflects the general tendency in the global car industry described above: since the level of automation in the core sectors of the car industry generally is high, there is no significant incentive to implement radically new schemes of digital manufacturing.

By contrast, major restructuring of production schemes and value chains is currently happening in the NEV-sector and among car suppliers at the mid- and lower ends of supply chains (Lüthje 2018).

In *NEV*, manufacturing volumes are still rather low and subject to frequent changes of models, technical standards and government requirements. Against this background manual assembly prevails among indigenous Chinese carmakers. Major global car firms so far have mostly integrated electrified models into their existing assembly operations, based on the platforms for their traditional cars. The NEV-production quota imposed by the Chinese government in 2018 may change this situation significantly, since the manufacturing volumes of NEV have to be heavily increased[11]. Major multinational carmakers recently have started to dedicate entire factories to volume production of NEV, such as FAW-VW with its ultra-modern plant in Foshan, using VW's new dedicated platform for electric vehicles[12].

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[9] *Handelsblatt*, July 7/8/9, 2017, p. 13

[10] The term refers to the transition between the pre-2007-2009 context when China economic growth was double digit, to the present situation when the average economic growth has been around 6-7%.

[11] Up to 2018, the NEV policy consisted mainly in subsidizing the purchase of Electric Vehicles and their production. As subsidies will progressively phase out from 2019 to 2021, car makers will have to sell a certain percentage of NEVs in their sales: targets for 2019 and 2020 are respectively of 10% and 12%. However, based on their energy efficiency and electric range, each EV sold can count up to 6 times more than a conventional vehicle (Muniz, Belzowski, and Zhu 2019)

[12] 2017-18 field interviews; *VW Group doubles capacity of South China plant;* Automotive News China, June 26, 2018

In the *car supply industry*, automation and digitalization is driven by two factors. Major Chinese second- or third-tier car suppliers, such as CITIC Dicastal in wheel alloys or Desai in car electronics, have developed extensive automation projects in production and supply chain management. Some of them host model projects for factory automation under Made in China 2025. These companies represent the type of mid-market mass manufacturer described above, that is transforming large-scale assembly operations from mainly manual to semi-automated processes. However, the nature of this rationalization is rather conservative, with a strong focus on cost cutting, quality improvement and expansion of manufacturing databases. In car electronics, this development intersects with the transformation to NEV production, since some of the major Chinese producers also engage in the manufacturing of battery control systems or battery packs and cells[13].

At the lower ends of auto supply chains, basic processes of metal parts manufacturing, such as grinding, milling and polishing, are the typical application fields for low-end robots. Such robots are typically used to displace semi-skilled migrant workers with long work experience and relatively high wages, who are difficult to find in local labour markets. Automation of this kind replaces the best-paid groups of migrant workers, but usually there is no retraining to qualify them as operators or programmers for automated equipment (Butollo and Lüthje 2017)[14].

A recent study of the automation and labour policies of car suppliers in South China confirms the dynamics of catch-up automation under the conditions of China's "new normal" (Yang 2018). The study included ten tier-one and tier-two suppliers for Chinese-Japanese joint ventures in the Pearl-River Delta. All of them had been involved in a major wave of labour conflicts in 2010 and subsequently participated in the introduction of democratic union elections and collective bargaining at plant level, seen as a model for China. Production processes in those companies have been continuously automated in recent years and became more capital intensive. Automation, however, is mostly gradual in nature, designed to improve quality, efficiency and to lower labour costs. Digital technologies and robots do not play a prominent role in the rationalization strategies of those companies, Made in China 2025 and the related local policies cannot be seen as a major driver for shop-floor change.

Automation clearly has an impact on workplaces and workers, but in no way as dramatic as the political slogan "robot replaces men" would suggest. In this particular case automation is used to compensate for higher labour costs supported by the newly established collective bargaining system, but it is not part of an overall assault on workforces and their improved collective rights. Rather, cooperative labour relations based on "moderated mobilization" of workers and mild concessions by managers prevail. The workers experience intensification of work and stricter control, but they do not see their jobs immediately threatened. However, they do expect higher wages and a fair share in productivity gains and economic profits, as well as a more rational structure of the wage system that would remunerate the skill improvements and greater efforts required from the workers. Collective bargaining, so far has not much addressed these topics, and remains relatively weak due to its limitation to single factories. But definitely, there is room for qualitatively oriented bargaining strategies as well for industry-wide bargaining at local level.

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[13] 2017/18 company interviews.

[14] 2017/18 company interviews.

Conclusion

In this article we have used the framework of performativity to deconstruct the determinist premises of digital manufacturing revolution concepts such as industry 4.0, advanced manufacturing and China 2025. We have shown that as other hypes and fashions these are concepts that aim at bringing into being "improbable futures" and not descriptions of current "disruptive" trends and transformations. As these concepts become popular and capture firms' and state's action, the probability that their visions of the future become true increases, but their chances of turning into self-fulfilling prophecies remain low. As exemplified by several case studies in organizational studies, STS and economic sociology, fashions and hypes eventually fade but do however have important side effects and can sometimes trigger profound transformations in the organization of production and work depending on their degree of performativity (F. Muniesa and Callon 2008).

In order to measure the degree of performativity of digital manufacturing concepts we have focused our attention on the automotive sector, which has been historically a pioneer in diffusing new manufacturing technologies and remains one of the main buyers of such technologies. The purpose of our analysis has also been to reconnect empirically grounded studies of the evolution of manufacturing with the future of work, employment and manufacturing as a way to dismiss disruptive narratives of technological change and bring back politics and agency in the current debate.

There are some differences in the performativity of the three concepts analysed: while Industrie 4.0 and Made in China 2025 have successfully changed the discourse and agenda in the public and within the companies, the Advanced Manufacturing Initiative does not seem to have developed a similar impact.

To assess the scope for a digital manufacturing revolution to take place in the automotive sector, we have reviewed the historical evolution of automotive manufacturing technologies and organisations focusing in particular on the 1980s-1990s wave of automation. We have shown that previous major attempts of automating final assembly have failed because human based teamwork organizations have proved much more flexible and efficient in dealing with complex and constantly evolving assembly processes. Furthermore, we have also highlighted that the main reasons that have triggered these attempts in the past are not present anymore: namely important gaps in productivity and quality between leading and lagging firms; and shortages of skilled and unskilled manpower willing to work in automotive factories. The scope for a digital manufacturing revolution taking place in the automotive sector appears therefore limited taking also into account that these companies have already to cope with the huge capital costs implied by much more pressing issues such as the cleaning of internal combustion engines, the electrification of cars, and the development of autonomous vehicles.

The analysis of the three main "digital revolution" concepts in manufacturing in Germany (Industry 4.0), in the US (advanced manufacturing) and in China (Made in China 2025) has supported more than it has challenged our historical understanding of the future of manufacturing in the automotive sector. Industrie 4.0 and the Advanced Manufacturing Initiative appear partially as traditional political projects driven by consortiums of dominant industrial firms whose aim is mainly to attract public funding to finance R&D efforts and to support market seeking strategies in a context of crisis and growing international competition. The automotive sector is more involved in Germany than in the US, but in both cases there is no evidence of major disruptive breakthrough of completely new technologies and organizational models – the "smart factory" is evolving in small steps. What we have observed are various forms of experimentation with new digital technologies in Germany, and a catch-up automation (the accelerated replacement of older machines by more advanced ones) in the US. In the case of China 2025, the project of a cloud based customer-driven manufacturing system controlled by domestic internet giants has the potential of being "disruptive", but this is still for the time being a vision whose implementation is problematic and whose future impacts need to be further assessed. Furthermore, it does not concern the automotive sector – the main Chinese industrial sector. As far as the automotive sector is concerned, the scope for major jumps towards digital cloud-based manufacturing appears again very narrow due to the already high capital intensity of existing factories and the limited applications of these technologies in mass production.

Our analysis dismisses the idea that a fourth industrial revolution is under way and that a radical disruptive break will take place in the coming years. In the short term, we rather expect a path-dependent evolutionary trend. It is unclear at the current stage, if the new technologies might have a more transformative character on work and employment in the middle- and long-term. But even if we assume some disruptive potential, the full development and implementation of concepts like Industrie 4.0 or Advanced Manufacturing will be a process of decades and not years.

However, behind the narratives of revolutionary breaks we have seen that more subtle changes are taking place on the shop-floor of automotive factories. These changes can be the direct consequences of the piecemeal introduction of some new digital technologies (in Germany), or the more indirect outcome of manufacturing revolutionary narratives as they create favourable conditions (notably public subsidies) for replacing existing machines with more sophisticated one (in the US) or for introducing standard cheap robots in small and medium suppliers (in China). What these changes have in common is that they concern the same category of workers: the skilled and semi-skilled workers who occupy strategic positions in the labour market and in the power relations in companies and firms. The threat is not only deskilling, but also the segmentation and polarisation of this group of workers as a way to reduce both labour costs and the scope for collective bargaining in a context of already increasing flexibilisation and intensification of work (Pardi 2017).

If, as we argue, the future of technology and manufacturing is open, because “it consists of an evolving range of possibilities from which people choose” (Noble 1984, xii), then current debates about the future of work tend to overlook the political dimensions involved at every level of these processes of technological change: from the national level, where the capture of state action and resources by private interests is a political issue; to the company and factory level, where technological change does not seem to lead to social progress in a context where human agency remains a fundamental resource for complex manufacturing processes. From this perspective the future of work in the automotive sector crucially depends on how trade unions and social partners, but also social sciences and political actors address these narratives of “disruptive change” and make of the “future of work” a matter of debate (rather than consensus) and of political choices (rather than technological necessities).

What trade unions and social partners can do in particular to shape these processes of technological change? We believe that they should start by not accepting these narratives as given; they should question the bias built in these visions by using and sharing the knowledge of real work situations and experimentations, and by cooperating with universities and social scientists in order to build a collective empirically grounded understanding of on-going and forthcoming processes of technological change. As we have shown in the case of the automotive industry, even in routine based standardised jobs in the assembly line, when product complexity and variability is high, human work and tacit collective skills remain central in order to cope with uncertainties and non-standard work situations. Trade unions should pay attention to the status of this “real” collaborative work, the recognition of the tacit skills involved, as well as the conditions under which these skills are integrated (or not) in new digital manufacturing system. Trade unions should try notably to be actively involved in the design and implementation of these technologies whenever possible. They should challenge in particular the top-down revival of the “high technology” drive for automation for the sake of automation pushed by consultants and technology providers, and engage with local engineers and factory managers in bottom-up “human fitting and motivating” automation strategies. Finally, social partners and trade unions should also be vigilant concerning the production and collection of data generated by these new technologies, as it could be used to control and intensify work. Evidences from the logistic sector show that when this is the case, then work conditions worsen, health and safety problems arise, and this vicious circle can be used as an argument for further automating work (Gaborieau 2012). Ultimately, all these initiatives should converge towards an alternative human-centred vision of the “future of work” than the one produced and diffused by global consultants and corporate and financial actors.

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