GROWINPRO

Growth Welfare Innovation Productivity

Working Paper

Industry 4.0: revolution or hype? Reassessing recent technological trends and their impact on labour

Alessandro Nuvolari
Armanda Cetrulo
Institute of Economics & EmbeDS, Scuola Superiore Sant'Anna, Pisa, Italy

15a/2019 August

This project has received funding from the European Union Horizon 2020 Research and Innovation action under grant agreement No 822781

Industry 4.0: revolution or hype?
Reassessing recent technological trends and their impact on labour.

Alessandro Nuvolari^[1] and Armanda Cetrulo^[2]

^Institute of Economics & EmbeDS, Scuola Superiore Sant'Anna, Pisa, Italy

Abstract

The aim of this paper is to reassess the current view of current technological trends adopting an historical perspective on previous industrial revolution. In our interpretation, the historical record provides some suggestive evidence for a more sceptical view of the notion of an emerging "fourth" industrial revolution. Indeed, even at an impressionistic glance, the recent developments in AI, communication and robotics that are marked as the core of the fourth industrial revolution, appear as a rather natural prolongation of the ICT macro-trajectories described in this paper. At the same time, in order to study the relation between technology and labour, we depict the plant as a preferential context to briefly look at the complex interaction between management systems, labour process and technological innovation. In this sense, we consider two Internet of Things' technologies in order to underline the persistence of a specific element characterizing capitalist mode of production, that is the exertion of control over workers. Consistently, we envisage a continuity between emerging management practices and previous management systems, especially referring to the ones adopted during ICT revolution.

Keywords: Industry 4.0, ICT revolution, management system, control

Acknowledgements: The authors acknowledge support from European Union's Horizon 2020 research and innovation programme under grant agreement No. 822781 GROWINPRO – Growth Welfare Innovation Productivity.

1. Introduction

Most of the current reflection on the impact of technological change on the labour markets and on the forms of work organization is formulated against the background of the notion of a "fourth" industrial revolution (Schwab, 2016) or of a radical technological transition (Brynjolfsson and McAfee, 2014). The aim of this paper is to reassess this view of recent technology trends adopting an historical perspective on previous industrial revolution. As we shall see, in our interpretation, the historical record provides some suggestive evidence for a more sceptical view of the notion of an emerging "fourth" industrial revolution. Relatedly, assessments of the impact of ICT technologies on employment that are rooted in the notion of a rapid large scale transition to a new era of automation are probably too sanguine and extreme (Frey and Osborne, 2013). Rather, we believe that if there are resemblances with previous industrial revolutions, we are witnessing today to a long wire-drawn historical process characterized by strong continuity with previous developments of ICT technologies. Interestingly enough, this different assessment of current technological trends still recognizes that the integration of new technologies in the economic and social system can be coupled with detrimental effects on employment, the quality of work and inequality. The rest of the paper is organized as follows. The following section discusses the notion of the fourth industrial revolution, taking stock of the literature on previous industrial revolution. Section 3 provides an overview of the complex interactions between the current configuration of ICT technologies and the labour market. Section 4 draws conclusions.

2. A fourth industrial revolution ?

The notion of the "fourth" industrial revolution is based on the idea that we are witnessing a constellation of technological breakthroughs (artificial intelligence, internet of things, advanced robotics, etc.) that have the potential to unleash a radical re-articulation of the economic system, possibly leading to a sustained phase of economic growth. In this respect, the first

[1] Alessandro Nuvolari, Scuola Superiore Sant'Anna & EMbeDS, Institute of Economics Piazza Martiri della Libertà, 33, 56127 Pisa, Italy; alessandro.nuvolari@santannapisa.it
[2] Armanda Cetrulo (corresponding author), Scuola Superiore Sant'Anna & EMbeDS, Institute of Economics Piazza Martiri della Libertà, 33, 56127 Pisa, Italy; armanda.cetrulo@santannapisa.it

point that merits attention is that aggregate productivity estimates do not seem to support the view of an incumbent industrial revolution. In fact, there seems to be a disconnection between analyses carried out at relatively "micro" level (technologies, firms, sectors) and analyses more focused on productivity measurements and aggregate growth. It is actually curious that, at the same time that the notion of a fourth industrial revolution is being expounded, other scholars put forward a much more pessimistic assessment of the potentialities of current technological trends, arguing that today inventions have a relatively limited effect in terms of improvement of living standards and of the rates of economic growth (Gordon, 2016) or that we are actually heading towards a "secular stagnation" (Summers, 2014).

Of course, it is well known that the impact of new technologies on productivity growth may be affected by severe delays. This is actually what the historical records concerning the past industrial revolutions suggest (Freeman and Soete, 1990). However, our contention is that, in this case, the issue is actually broader than the delays that can affect the emergence and consolidation of a new "techno-economic" paradigm. The key-issue in our view is whether it is appropriate to regard the current technological trends in ICT as a structural discontinuity: "Digital technologies that have computer hardware, software and networks at their core are not new, but in a break with the third industrial revolution, they are becoming more sophisticated and integrated and are, as a result, transforming societies and the global economy" (Schwab, 2016, p. 12). In a related paper (Nuvolari, 2019), one of us has stressed that the life-cycle of many technologies that are the constituting elements of the "techno-economic" paradigms identified by Neo-Schumpeterian scholars such as Freeman, Louca and Perez (Freeman and Louca, 2001) are characterized by extremely protracted life-cycles, spanning in many cases more than a century. This point has actually been acknowledged also by Freeman and Louca (2001, p. 145), who, nonetheless, decided to stick to the traditional Kondratiev-wave chronology. On further reflection, however, the traditional chronology in terms of first, second and third industrial revolution seems more heuristically incisive (Nuvolari, 2019). Consider the case of steam-power. The peak of use of steam-power in a leading-economy such as Britain is actually the beginning of the XX century. In quantitative terms, this is the genuine "age of steam". More explicitly, we are witnessing an extremely protracted life-cycle, spanning from the first half of the XVIII century to the first half of the XX century. For this reason (see Nuvolari, 2019, for a more extensive discussion), the traditional "three" industrial revolutions chronology with its broad flexibility seems more insightful than the more rigid Kondratiev chronology, which identifies the role of steam-power in the second Kondratiev, 1848-1895 (Freeman and Louca, 2001, p. 140).

Similar considerations may be put forward concerning the emergence and development of ICT technologies. Table 1 provides a synthetic description of the constellation of the technological advances of the ICT revolution. In our view, this constellation may be regarded as encompassing four main technological clusters: electronic components, computers, software and networking equipment. Table 1 suggests three important points. First the convergence between computer technologies with advances in communications, which is one of the hallmarks of the recent "hype" of the fourth industrial revolution, it is something that was already taking place in the late 1980s/early 1990s (Freeman and Soete, 1990). The second point is that, as in the case of previous industrial revolutions, also the streams of technological advances of the ICT revolution are characterized by different paces of progress (compare the proverbial "Moore's law" for components, with the so-called "Whirt's law" arguing that the slow speed of development in software more then compensates the extremely rapid advance in semiconductors). If this is the case, extrapolating, rates of technological developments by very specific technologies or applications can lead to gross overestimations of the impact of technical change. The third point is that, even at an impressionistic glance, the recent developments in AI, communication and robotics that are marked as the core of the fourth industrial revolution, appear as a rather natural prolongation of the four macro-trajectories described in Table 1.

Table 1 around here.

3. Technology and labour

In order to investigate the impact on labour of "Industry 4.0" technologies, we avoid discussing the emergence of a polarization trend - whether skills or routine biased - (for a recent review, see Piva and Vivarelli, 2018); neither we orient our analysis towards any kind of forecasting on the number of jobs that will be respectively destroyed and created (Frey and Osborne, 2017; Arntz et al., 2016). Interestingly, these studies seem to recognize the resilience of some eminently human attitudes to mechanization (Clark, 2007, pp. 287-289) and the importance, for instance, of human dexterity and social intelligence. However, they tend to reveal, at different degree, a substantial theoretical weakness in framing technological change essentially as a deterministic exogenous factor (usually proxied by the decline in the price of the computer), where labour is seen as a replaceable input of the production function.

Tracing back to classical economists (Usher, Baggage, Smith) and prominent scholars (Braverman, 1974), we focus the attention on the relation between technology and labour looking at arising challenges in terms of job content, work organization and, presumably, international division of labour. In fact, even recognizing the importance of discussing the effects of technological change on employment, we register the absence of as much pervasive and comprehensive debate on the actual and potential changes on the labour process as a whole. We detect three possible levels of analysis, each one offering a different and complementary viewing angle:

- the *plant* level, where new machineries are directly installed and adopted and where mechanisms of tasks parcelling, deskilling and/or autonomy enhancement can be studied from a micro perspective;
- the *platform* level, that constitutes a real innovation in terms of new business management model;
- the ”*planet*” level, where the relation between the fragmentation of the production process through global value chains and the use of new technologies can be scanned.

Our original aim is to identify common and diverse traits across the three levels, asking whether we are experiencing a radical rupture in terms of technology, quality of work and management systems or rather a revival of old and enduring practices dressed up with new tools. Nevertheless, in the present work we will elaborate on the first level only, leaving the development and comparison of the other two to future study.

3.1 A premise

In our view, the adoption of a specific technology within firms is not neutral neither deterministic, but it depends on the complex interaction of knowledge and dynamic capabilities (Zollo and Winter, 2002) from one side, and distribution of power between capital and labor on the other (Braverman, 1974). For this reason, the study of the relation between technological innovation and labor within organizations unavoidably implies the understanding of the evolution of management systems devoted to governing these changes. During the Eighties, the introduction of the “Lean system/thinking” in Us and other developed countries (Womack et al., 1990; Ohno, 1988; Florida and Kenney, 1991) brought, with respect to the Fordist organization of labour, a set of important changes briefly summarized by the kan-ban or Just in Time Production (Musso, 2013).

If divergences with respect to the Ford-type rigid organization were evident as in the case of “move the metal” imperative opposed to the Toyota obligation of stopping the assembly line to remove a bottleneck (consistently with the theory of *kaizen*), the departure of Lean from Taylorism has been highly controversial (Harrison, 1997). Even the same proponents of the Lean system, such as Ohno, did not want to depart from Taylor, but just “think it on the contrary” (Coriat, 1991). Indeed, several evidences have been produced showing an increasing workload and standardization, functional in this case, to enhance workers direct involvement in a continuous improvement process (Adler, 1995 defines it as ”democratic taylorism”).

Hailed as the beginning of a new era, characterized by up-skilling, workers empowerment and the recognition of the limits of Fordist labour division (Kern and Schumann, 1987), already at the dawn of the ICT technological revolution, it was possible to identify the emergence of new Taylorist forms, related in particular to the adoption of computers (Lutz, 1992; Manske, 1990). In this setting, a new type of management, in line with the Human Resource Theory, was necessary to ensure a higher degree of attentiveness and cohesion among workers, with the final aim of increasing quality and cutting costs, as predicted by Toyotism (Osterman, 1994).

At the same time, the progressive weakening of trade unions (Baccaro and Howell, 2017) together with the more general transformation of western countries’ institutions in terms of welfare, capital control and industrial relations (Streeck and Thelen, 2005), made easier to push for an increasing labour flexibility, demanded first by producers to deal with strong market competition and then endorsed by international organisations (OECD, 1994) to propel growth and productivity. At the same time, the labour share in the functional income distribution narrowed while the gap between productivity and wage growth was widening (Dosi and Virgillito, 2019).

In this sense, it is interesting to pinpoint an element of discontinuity with respect to previous revolutions impact on employment and, more specifically, on wages. As Allen (2017) has noted, following the first industrial revolution, in Western countries, from the second half of the nineteenth century real wages began to track productivity improvements, so that there was a significant redistribution of the fruits of technical progress to a wide section of society. Clark points out that, since the industrial revolution, notwithstanding the increase of mechanization and automation did not result in a systematic deterioration of the wages of unskilled workers. Actually, according to Clark (2007, p. 276), the available estimates suggest that this skill premium was significantly higher in the pre-industrial period (around 100 per cent) than in industrial societies (about 25 per cent).

Therefore, current industry 4.0's transformations have to be read accounting for the changes cited above and starting from the assumption that one of the persistent elements of the capitalist mode of production is the exertion of control[3] over workers (Edwards, 1982), shaped by competition and financial markets. Control is indeed necessary to obtain workers' consent (or simply passivity) to the extraction of surplus (Burawoy, 1982) and to enforce effective discipline mechanisms (more or less explicit) from fines on wages (Pollard, 1963) and foreman supervision (Marglin, 1974) in the first factories, to wearable technologies nowadays (Moore and Robinson, 2016).

It is in the light of these issues that we look briefly at the current adoption in the workplace of two specific Internet of Things related technologies. Clearly, our choice is very limited with respect to the entire set of machines and technologies (for a recent review see Martinelli et al., 2019). However, it is guided by the urge of stressing the existence of a constant element characterizing modes of production in terms of surveillance over the workforce, a trait which has been already reinforced with ICT revolution and that can now reach its peak in terms of efficacy and pervasiveness.

3.2 Internet of things and the workplace

Internet of things can be defined as "as a global network infrastructure composed of numerous connected devices that rely on sensory, communication, networking, and information processing technologies" (Li et al., 2015, p. 2233). It allows the collection, storage and transmission of a vast amount of information. IoT usage is expanding in several and different contexts, from health care and environment protection to manufacturing and service. Two of the technologies belonging to IoT sensive layer - RFID and WSN - are particularly interesting for our analysis.

The *RFID* or Radio Frequency Identification system essentially consists in reading a tag, also called "transponder", attached to an object, in order to identify and track the object. Data are stored in a microchip and transmitted through an antenna, both contained in the tag. According to their power source, tags can be defined active, if they have their own battery, or passive, if instead they take power from the tag reader (Kumar et al., 2009). Diffused well before the advent of Industry 4.0 as the innovative successor of the bar code scanning, RFID technology is nowadays broadly adopted in logistics, food, automotive and health care sector. More generally, it is widely used in supply chain management since it ensures a precise real time tracking of inventories.

Not only stocks, but employees as well can potentially be tracked continuously through, for example, their Identification Badge in order to know, for instance, not only when they start and finish to work, but also the time spent in the bathroom (Pagnattaro, 2008). If mail monitoring allowed employers to control the contents of communications exchanged among workers, RFID and GPS technology can follow all workers' movements, within and outside the plant (Ciocchetti, 2011).

[3] As recalled in Knights and Willmott (1990, p.6), Marx pointed out this issue very clearly: "As the number of the co-operating workers increases, so too does their resistance to the domination of capital, and necessarily, the pressure put on by capital to overcome this resistance . The control exercised by the capitalist is not only a special function arising from the nature of the social labour process, and peculiar to that process, but is at the same time a function of the exploitation of a social labour process, and is consequently conditioned by the unavoidable antagonism between the exploiter and the raw materials of his exploitation" (Marx, 1976, p. 449).

With *wearable technologies* we refer here to the set of accessories, such as smart-watches, wrist bands, and e-textiles (i.e. smart shoes and gloves), that can be easily worn by individuals without a specific medical procedure (Seneviratne et al., 2017). Forecasts speak of a significant growth of their market[4]. Indeed, one half of industrial players in manufacturing are expected to use wearable technologies by 2022, according to Zebra[5]. These technologies are described as powerful tools capable of improving the safety and productivity of workers, through the constant tracking of their activities, from the number of steps (Schatsky and Kumar, 2018) to the daily level of glucose (Fitbit, 2019). However, several issues arise in terms of privacy and data collection. Wearable technologies and RFID as well, can potentially be used to enforce a pervasive surveillance system, where each action or verbal exchange of workers can be stored, "quantified" (Moore and Robinson, 2016) and assessed arbitrarily by employers. Data can potentially be used to discriminate employees according to their health state, the speed in performing a task, or the ability to reduce distractions and unnecessary breaks in a working day. In this sense, their adoption in the workplace represents a specific management strategy with significant effects in terms of control, even if initially presented to workers in terms of wellness or productivity projects (Moore et al., 2018).

4. Concluding remarks

The upshot of our previous considerations is that rather than witnessing a sudden shift to a world without work, it is more likely that we are in front of a complex and long-drawn process of transformation rooted in the emergence and consolidation of ICT technologies, even if in a profoundly evolving institutional context.

In this respect, the simultaneous deterioration in workers rights and industrial relations quality (Baccaro and Howell, 2017) with respect to "regulation regimes" (Aglietta, 2000) can play a role in orienting technological change towards a path that reflects current hegemonic interests and unbalanced power distribution between capital and labour (Noble, 1978). It might become a fundamental priority, easily implementable in the near future, to proceed with the achievement of the genuine Taylor's scientific management objectives of fully separate "conception" from "execution", standardize procedures and parcel tasks rather than, for instance, massively improve the ergonomics of all weary jobs in manufacturing sectors and reduce working time.

In fact, the current development and adoption of some of the technologies belonging to the Industry 4.0 taxonomy, as the ones considered in this study, enables a continuous control and flow of data of individual working activities, such that it might be unnecessary to exert any kind of positive incentive to ensure workers' participation and obedience in a highly disciplined, even if implicitly, context (Moore and Robinson, 2016). Concomitantly, these changes can hamper a systematic transmission of skills with informal mechanisms such as learning-by-doing and other forms of on the job training (Bessen, 2015).

On the other hand, fragmentation of the production process and disaggregation of the labour force make it difficult for a unified and effective conflict strategy to emerge. When the strict relation between the level of efforts exerted and the quantity of the piecework was evident, workers could directly react to forms of exploitation, in the first instance reducing their effort or hiding personal abilities in performing that task (Bonazzi, 2007, p.180). Now that the link between individual effort and final product is extremely difficult to grasp, even for those directly involved in the production process, workers' reactions have to surge differently.

One starting point would be to question the mainstream narrative that describes technological change as a deterministic and neutral process, claiming instead its social and political dimension (Braverman, 1974; Noble, 2017), with the final aim of opening up a general discussion on modes of production, output and value distribution.

[4] https://www.abiresearch.com/market-research/product/1032426-wearable-device- market-share-and-forecasts/, https://www.idc.com/getdoc.jsp?containerId=US44718719

[5] https://downloads.zebra.com/us/en/about-zebra/newsroom/press-releases/2017/zebra- study-reveals-one-half-of-manufacturers-globally-to-adopt-.html

In addition, further empirical investigations on the use and dissemination of these technologies, that stand in continuity with a broader system of "ICT surveillance", is necessary[6]. In particular, identifying possible disputes in terms of privacy, labour regulation and industrial democracy is at the very least essential in order to deepen one of the most relevant issues concerning the relationship between technology and work, together with the emergence of new forms of digital labour (De Stefano, 2015). As in the case of previous industrial revolutions, a proper mix of economic and social policies will be required in order to make sure that technological advances do not lead to increasing inequality and to the disarticulation of the social fabric.

References

Adler, P. (1995). 'Democratic Taylorism': the Toyota production system at NUMMI. *Lean work: Empowerment and exploitation in the global auto industry*: 207-219.

Allen. R. (2017). Lesson from history for the future of work, *Nature*, v.550, pp. 321-324.

Aglietta, M. (2000). *A theory of capitalist regulation: The US experience*. Verso, 2000.

Arntz, M., Gregory, T. and Zierahn, U. (2016), The Risk of Automation for Jobs in OECD Countries: A Comparative Analysis, *OECD Social, Employment and Migration Working Papers*, No. 189, OECD Publishing, Paris.

Baccaro, L. and Howell, C. (2017). *Trajectories of neoliberal transformation: European industrial relations since the 1970s*. Cambridge University Press.

Bessen, J. (2015). *Learning by Doing. The Real Connection between Innovation, Wages and Wealth*, Yale University Press, New Haven.

Bonazzi, G. (2007). *Storia del pensiero organizzativo*, Volume 367. FrancoAngeli.

Braverman, H. (1974). *Labor and monopoly capital*. New York: Monthly Review .

Brynjolfsson, E. and McAfee, A. (2014). *The Second Machine Age*, W. Norton, New York.

Burawoy, M. (1982). *Manufacturing consent: Changes in the labor process under monopoly capitalism*. University of Chicago Press.

Ciocchetti, C. A. (2011). The eavesdropping employer: a twenty-first century framework for employee monitoring. *American Business Law Journal* 48 (2), 285–369.

Clark, G. (2007). *A Farewell to Alms*, Princeton University Press, Princeton.

Coriat, B. (1991). *Penser à l'envers*. Ch. Bourgois.

De Stefano, V. (2015). The rise of the just-in-time workforce: On-demand work, crowdwork, and labor protection in the gig-economy. *Comp. Lab. L. & Pol'y* J. 37, 471.

[6] For instance, the American Management Association and The ePolicy Institute certified in 2007 an intense use of computer monitoring by employers in order to increase productivity and lower cases of litigation (http://www.plattgroupllc.com/jun08/2007ElectronicMonitoringSurveillanceSurvey.pdf).

Dosi, G. and Virgillito, M. E. (2019). Whither the evolution of the contemporary social fabric? new technologies and old socio-economic trends. Technical report, *GLO Discussion Paper*.

Edwards, R. (1982). Contested terrain: The transformation of the workplace in the twentieth century. *Science and Society* 46 (2):237-240 (1982)

Fitbit (2019). *The impact of diabetes on the workplace,* available at https://2nwchq3a3ags2kj7bq20e3qv-wpengine.netdna-ssl.com/wp-content/uploads/Impact-Diabetes-Workplace-WP-1.pdf .

Florida, R. and Kenney, M. (1991). Transplanted organizations: The transfer of japanese industrial organization to the us. *American Sociological Review*, 381–398.

Freeman, C. and Louca, F. (2001). *As time goes by: from the industrial revolutions to the information revolution*. Oxford University Press.

Freeman, C. and Soete, L. (1990). Fast structural change and slow productivity change: some paradoxes in the economics of information technology, *Structural change and economic dynamics*, vol. 1, pp.225-242.

Frey, C. B. and Osborne, M. A. (2017). The future of employment: how susceptible are jobs to computerisation? *Technological forecasting and social change* 114, 254–280.

Gordon, R. (2016), *The Rise and Fall of American Growth*, Princeton University Press, Princeton.

Harrison, B. (1997). *Lean and mean: The changing landscape of corporate power in the age of flexibility*. Guilford Press.

Kern, H. and Schumann, M.(1987). Limits of the division of labour. new production and employment concepts in west german industry. *Economic and Industrial Democracy* 8(2), 151–170.

Knights, D. and Willmott, H. (1990). *Labour process theory*. MacMillan Press LTD

Kumar, P., Reinitz, H., Simunovic, J., Sandeep, K. and Franzon, P. (2009). Overview of rfid technology and its applications in the food industry. *Journal of food science* 74(8), R101–R106.

Li, S., Da Xu, L. and Zhao, S. (2015). The internet of things: a survey. *Information Systems Frontiers* 17(2), 243–259.

Lutz, B. (1992). The contradictions of post-tayloristic rationalization and the uncertain future of industrial work. *Technology and Work in German Industry, Routledge and Keagan*, London, 26–45.

Manske, F. (1990). The end of taylorism or its transformation? From spot control to systemic control of the production process. *International Journal of Political Economy* 20(4), 61–78.

Marglin, S. A. (1974). What do bosses do? The origins and functions of hierarchy in capitalist production. *Review of radical political economics* 6(2), 60–112.

Martinelli, A., Mina, A., & Moggi, M. (2019). The Enabling Technologies of Industry 4.0: Examining the Seeds of the Fourth Industrial Revolution (No. 2019/09). *Laboratory of Economics and Management (LEM), Sant'Anna School of Advanced Studies, Pisa, Italy.*

Marx, K. (1976). *Capital* (vol. 1). Harmondsworth: Penguin.

Moore, P., Piwek, L. and Roper, I. (2018).The Quantified Workplace: A Study in Self-Tracking, Agility and Change Management. *Self-Tracking*. Palgrave Macmillan, Cham, 93-110.

Moore, P. and Robinson, A. (2016). The quantified self: What counts in the neoliberal workplace. *New Media & Society* 18(11), 2774–2792.

Musso, S. (2013). Labor in the third industrial revolution: A tentative synthesis in Dosi, G., & Galambos, L. (Eds.) *The third industrial revolution in global business*. Cambridge University Press.

Noble, D. F. (1978) Social choice in machine design: The case of automatically controlled machine tools, and a challenge for labor. *Politics & Society* 8.3-4: 313-347.

Noble, D. (2017). *Forces of production: A social history of industrial automation*. Routledge.

Nuvolari, A. (2019). Understanding successive industrial revolutions: a "development block" approach. *Environmental Innovation and Societal Transitions*, forthcoming.

OECD (1994). *The Oecd jobs study: Facts, analysis and strategies*.

Ohno, T. (1988). *Toyota production system: beyond large-scale production*. crc Press.

Osterman, P. (1994). How common is workplace transformation and who adopts it? *ILR Review* 47(2), 173–188.

Pagnattaro, M. A. (2008). Getting under your skin-literally: Rfid in the employment context. *U. Ill. JL Tech. & Pol'y*,237.

Piva, M. and M. Vivarelli (2018). Innovation, jobs, skills and tasks: a multifaceted relationship. *Giornale di diritto del lavoro e di relazioni industriali.*

Pollard, S. (1963). Factory discipline in the industrial revolution. *Economic History Review*, 254–271.

Schatsky, D. and N. Kumar (2018). Workforce superpowers: Wearables are augmenting employees' abilities. *Deloitte Insights.*

Schwab, K. (2016), *The Fourth Industrial Revolution*, World Economic Forum: Geneve.

Seneviratne, S., Y. Hu, T. Nguyen, G. Lan, S. Khalifa, K. Thilakarathna, M. Hassan, and Seneviratne, A. (2017). A survey of wearable devices and challenges. *IEEE Communications Surveys & Tutorials* 19(4), 2573–2620.

Streeck, W. and K. A. Thelen (2005). *Beyond continuity: Institutional change in advanced political economies*. Oxford University Press.

Summers, L. (2014). US Economic prospects: secular stagnation, hysteresis, and the zero-lower bound, *Business Economics*, vol. 49, pp. 65-73.

Womack, J. P., J. P. Womack, D. T. Jones, and D. Roos (1990). *Machine that changed the world*. Simon and Schuster.

Zollo, M. and S. G. Winter (2002). Deliberate learning and the evolution of dynamic capabilities. *Organization science* 13(3), 339–351.

Table 1: The macro-trajectories of the ICT revolution.

Years	Semiconductors	Computers	Software	Networking
1940-1950	1947: Point contact transistor (Shockley, Brattain, Bardeen; Bell Lab)	1944: Colossus Mark II (Tommy Flowers; Bletchey Park)		
		1945: ENIAC(Eckert & Mauchly; University of Pennsylvania)		
1950-1960	1954: Silicon based transistor (Gordon Teal; Texas Instruments)	1951: UNIVAC I (Remington Rand)	1952: A-0 compiler (Grace Hopper)	
	1958: Integrated circuit (Jack Kilby, Texas Instruments)	1953: IBM 701 (IBM)	1957: FORTRAN	
	1958-9: Silicon oxide insulation in integrated circuit (Jean Hoerni, Robert Noyce; Fairchild)	1954: IBM 650 (IBM)	1960: COBOL 1960: LISP (John McCarthy)	
		1958: Solid state 80 (Sperry Rand)	1963: ASCII	
		1959: IBM 1401 (IBM)	1964: BASIC (Thomas Kurz, John Kemeny)	
1960-1970	1965: Moore's law (Gordon Moore; Fairchild)	1965: PDP 8 (DEC) [first minicomputer]	1964: OS/360 (IBM)	1960: Dataphone (1st commercial modem; AT&T)
	1967: MOS chip (Fairchild)		1969: UNIX (Kenneth Thompso, Dennis Ritchie; AT&T)	
1970-1980	1971: Intel 4004 micro-processor (Federico Faggin, Intel)	1973: Micral	1979: VisiCalc (Daniel Bricklin, Robert Franckston)	1970: ARPANET
	1972: Intel 8008 (Intel)	1975: Altair		1971: ALOHANET (University of Hawaii)
	1976: Zilog Z80	1977: Apple II (Steve Jobs and Steve Wozniak; Apple)		1973: Ethernet (Robert Metcalfe; Xerox PARC)
	1979: Motorola 68000	1979: Atari 800		1975: Telenet
1980-1990	1985: Intel 80386 (Intel)	1981: Osborne I (Adam Osborne)	1981: MS-DOS	
		1981: IBM 5150 (IBM)	1982: Lotus 1-2-3 (Mitch Kapor)	
	1986: optical transistor (David Miller; Bell Lab)	1982: Commodore 64 (Commodore) 1982: ZX Spectrum (Sinclair)	1983: GNU (Richard Stallman)	
		1983: Lisa (Apple)	1984: Mac OS (Apple)	
		1984: MacIntosh (Apple)	1985: Windows 1.0 (Microsoft)	

1990-2000	1993: Intel Pentium (Intel)		1990: Windows 3.0 (Microsoft)	1990: HTML (Tim Berners Lee, CERN)
			1991: LINUX (Linus Torvalds)	1993: MOSAIC (Eric Bina, Marc Andreesen; University of Illinois)

Source: Nuvolari (2019)