Will the Fourth Industrial Revolution deliver as promised?

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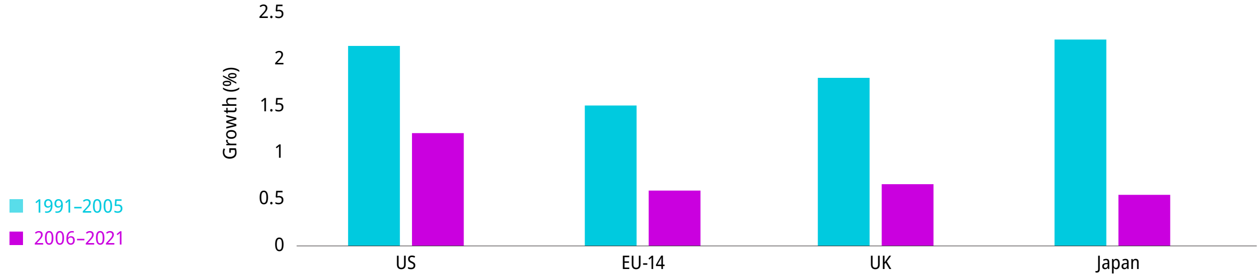
How promising has the digital revolution been so far?

It has been widely claimed that we are now in the midst of a Fourth Industrial Revolution, broadly characterized as the Digital Age.[1] Indeed, we are witnessing many of the same trends seen in previous industrial revolutions. Over the past half century a continuous stream of digital inventions has emerged with a broad-based diffusion and adoption of related technologies and applications driven by a rapid cost decline (see GII 2022 Tracker).

At the same time, many questions have been raised not only about the similarities to, but also the differences from, past experiences. At present, we have experienced almost two decades of slow productivity growth across most advanced economies, including the United States of America (US), Europe and Japan (Figure 1.1). There is a serious concern that such slow productivity growth will threaten economic progress, living standards and well-being in coming decades, and potentially bring the Fourth Industrial Revolution to an end before its positive impact has fully played out. This would be even more problematic in light of the current challenges we are facing, including the economic recovery from COVID-19, the transition to a net-zero CO_2 emission economy, and resets in the pattern of globalization and the functioning of the labour market.

Figure 1.1 Gross domestic product per hour worked, percentage growth, 1991–2021

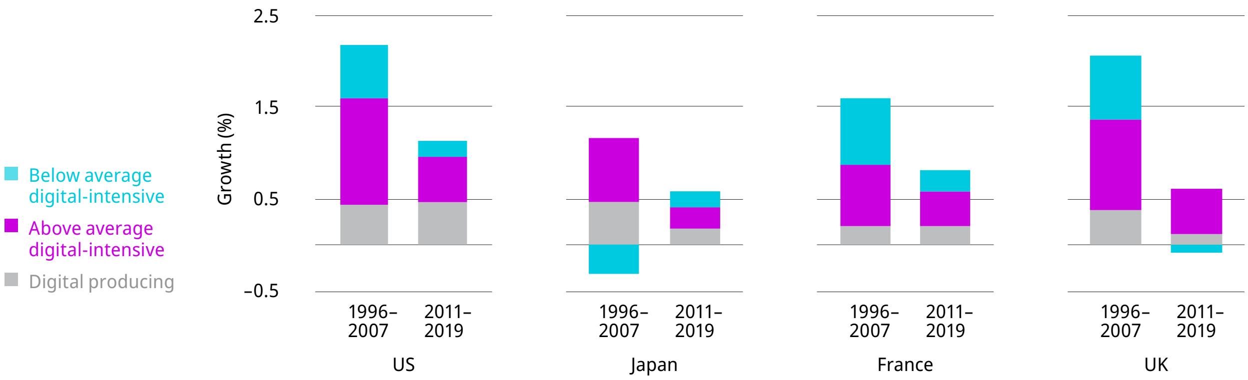


Source: The Conference Board, Total Economy Database, April 2022.

There has been some evidence that slowing innovation could be at the root of the recent slowdown in productivity.[2] Other reasons could be weak demand and counterproductive fiscal and monetary policies in the aftermath of the 2008–2009 global financial crisis. However, whether looking at the sector or industry level, or across particular technologies (such as the rapid adoption of the personal computer (PC), the rise of the internet and increased usage of digital business information), it is apparent there might be more change happening than what is observed in macro estimates.

Beneath slowing aggregate productivity growth rates, signs of structural improvements can be detected.[3] For example, in the United States, most of the positive contribution to productivity growth between 2011–2019 originated from the digital producing sector (Figure 1.2). In relative terms, France, Japan and the United Kingdom (UK) show the most intensive digital-using sectors making the largest contribution to productivity growth. In all four economies, the least intensive digital-using industries performed worst in both absolute and relative terms.

Figure 1.2 **Gross domestic product per hour worked, percentage contributions by digital productivity**



Source: De Vries, Erumban and van Ark (2021). Data for Japan were sourced from the Japan Industrial Productivity (JIP) database.

Note: Aggregation refers only to within-sector productivity, excluding any reallocation effect between sectors.

The key question addressed by this paper is whether we can be confident that the Digital Age will turn into a fully fledged industrial revolution, and what can be learned from past successful industrial revolutions to ensure we bring this transition – which we are currently in the midst of – across the finishing line, and avoid the biggest risks to it stalling.

We discuss the key characteristics of industrial revolutions from a historical perspective. The comparison teaches important lessons in terms of the need to increase knowledge diffusion, create absorptive capacity and enhance worker engagement. But such comparisons run the risk of comparing apples with oranges. Each industrial revolution represents a unique range of complex events that cause systemic changes across multiple spheres – technology and innovation, business and economy, science and education, politics and institutions.[4]

What characterizes an industrial revolution?

An industrial revolution can be characterized by the economic and social transformation that occurs as a result of a lengthy and complex interaction of technological change and investment in physical, human and intangible capital, along with the redefinition of how work gets done, how businesses are organized, and how social and political institutions provide support. Each revolution creates a need for novel worker skills with which to build, use and improve new technologies, as well as a need for time in which to adjust to the new social norms implicit in the revolutionary transformation. Importantly, each revolution brings new and less expensive energy sources – from water, to steam, to coal, to oil, to renewables (see GII 2022 Tracker). Each revolution also brings continuous process and product innovation, as creative destruction is complemented by personal and institutional transformation.

Each industrial revolution proceeds through two periods (Figure 1.3). During the installation period, the new generation of technology is immature and economic activity relies on the capital stock and business practices of the previous era. During the deployment period, that follows, capital gets renewed more broadly and the new technology takes on general-purpose characteristics, meaning it becomes cheaper and ubiquitous, and helps bring about fundamental transformations in economic, social and political institutions.[5]

Arnold Harberger describes the growth pattern during the earlier period as “mushroom” growth, meaning cost reductions occur in a limited number of sectors, industries and firms, which experience much improved productivity.[6] However, turning the new technologies into general-purpose technologies, or more broadly into industrial revolutions, requires their wider diffusion throughout the economy. The spread of new technology and innovation gives rise to new applications that eliminate bottlenecks and open opportunities for broad-based growth. In Harberger's terminology, "yeasty" growth during the later period leavens economic activity with broad externalities linked to the accumulation of knowledge creating economies of scale (see GII 2022 Expert Contribution from Petropoulos). The widespread adoption of a general-purpose technology with a substantial level of creative destruction and business process transformation results in robust overall growth and, eventually, in a more equal income distribution.[7]

Figure 1.3 Four industrial revolutions

	Installation			Global financial market crisis	Deployment	
	Eruption	Frenzy			Synergy	Maturity
1 Age of Steam and Railways	1829	"Rocket" Steam engine	Panic 1847	↓	• Standards on gauge, time • Catalog sales companies • Economies of scale	1873
2 Age of Steel, Electricity and Heavy Engineering	1875	Carnegie Bessemer steel plant	Depression 1893	↓	• Urban development • Support for interventionism	1920
3 Age of Oil, Automobiles and Mass Production	1908	Model-T mass production	Crash 1929	↓	• Build-out of interstate highways • IMF, World Bank, BIS	1974
4 Age of Information and Telecommunications	1971	Intel microprocessor announced	2008–2009 Great Recession	↓	• Potential deployment period ahead	

Source: Author's own elaboration of Perez (2002), p. 78.
Note: BIS is Bank for International Settlements; IMF is the International Monetary Fund.

Four economic phenomena characterize both periods: average age of the capital stock; rate of knowledge diffusion and absorptive capacity; responsiveness of the capital–labor ratio to changes in wages and interest rates; and the share of labor in total income.[8] During the installation period when new technology is at a nascent stage, capital growth slows as entrepreneurs hold on to capital from the previous era and knowledge diffusion is limited. Early automation of standard business processes by pioneering firms can result in capital substituting for labor.[9] The advent of the new technology gradually increases automation, lowers marginal costs and raises markups. At the same time, labor's income share falls at the aggregate level, driven by productivity-leading firms while most other firms still lag. During the deployment period, the new technology creates novel human tasks for which labor possesses a comparative advantage. The novel tasks reinstate labor, improve productivity and increase labor demand. Capital and labor are once again complementary.

As creative destruction evolves into a new social, political and economic regime, with novel opportunities appearing on the deployment period's horizon, workers are not just at the receiving end of technological change but contribute to a pressure for further change. With workers transforming their behavior, adjusting their compensation expectations and revising their career projections, pressure builds for transformation. Indeed, Yellen has hypothesized that productivity improvements can be realized, because higher real wages influence workers in a variety of ways, such as in reduced employment turnover.[10] Workers who feel they are treated fairly in terms of compensation, career advancement, education and training report high levels of job satisfaction and are more productive.[11] Especially in services industries, it is not just worker quality that is a source of productivity growth, but also worker engagement delivering higher service quality, driving further productivity improvement and a wider distribution of benefits – leading to higher living standards and improved well-being.

An illustration: The Second Industrial Revolution

The Second Industrial Revolution, during the last quarter of the 19th century through the first quarter of the 20th century, vividly illustrates the complex social and economic transformation described above. Technological change during this era involved a "war of the currents," that ultimately led to the establishment of an electrical power network and the setting of global standards.[12] Among the profound business process, product and social innovations that followed was the creation of the modern industrial enterprise.[13] The substantial capital investment in constructing the electric power network and building modern industrial enterprises subsequently spread social, political and economic benefits around the globe.[14]

While in certain industries select industrial enterprises emerged as superstar firms during this Second Industrial Revolution, the behavior of non-superstar firms – those lagging on innovation, with diminished competitiveness and lacking technological intensity – changed only very gradually, due to deeply rooted cultural barriers. Both British business leaders and workers jealously guarded the status-quo.[15]

In order for established British business leaders to remain successful, Lazonick asserts, "the strategy of living off his [existing] industrial capital was rational."[16] During the installation phase of the Second Industrial Revolution, fixed costs were low, inputs readily available, outputs sold in a known marketplace, and competition nearby and well understood. The required dramatic transformation of the social determinants of technological progress was beyond lived experience.

Once the electric power network had been installed, industrialists were challenged to develop their organizational capabilities, as observed, for example, by Chandler.[17] The new innovative and competitive landscape involved global competition and saw the rise of corporate enterprises. There was an increase in research and development (R&D) of new productive resources and in the interaction of organization and technology, as well as a rise in human resources and the commitment of financial resources. Nonetheless, with the technology now maturing, transformation was an opportunity for the laggards to narrow the gap, benefiting from greater knowledge diffusion and deeper absorptive capacity across a much wider universe of firms, especially in Germany, Switzerland and the United States. The requisite change in the strategic and operating model failed to flourish in Britain. British business leaders were unable to appreciate the returns available for innovative technology. Instead, it was their competitors who shaped the economic environment in ways Briitish leaders could not.[18] By the second decade of the 20th century, economic and social benefits in these countries had become widespread, with income and wealth growing rapidly.

Digital Age dynamics

The Digital Age is characterized by a combination of what are by now established digital technologies – the internet, mobile devices, cloud computing, simple machine learning – which are part of what can be labelled "Old Digital Economy," having emerged during the late 20th century. The emergent digital technologies of the "New Digital Economy" of the early 21st century provide "deep learning" applications in artificial intelligence (AI) based on neuro-technology. Realizing the possible benefits of these new digital technologies remains challenging. How and when Harberger's "mushroom" growth will become "yeasty" remains highly uncertain. For example, Van Ark argues that the maturation period for technologies in the "New Digital Economy" may be long, given the complexity of applying them within a business context.[19]

Opportunity notwithstanding, adoption of AI technology remains limited, making the case for their not yet having entered the deployment phase. Across AI-related technologies, for all firms in the United States, the aggregate adoption rate was only 6.6 percent in 2017, and highly skewed.[20] While the heaviest concentration was among a small subset of older and larger firms, an increasing number of new, young, born-on-the-web yet still quite small firms were also adopters. Cloud services displayed modest adoption in 2017, with a large share of firms hosting at least one information technology function in the cloud. But cloud usage was still significantly lower than the adoption rate for digital business information, which was nearly universal.

Currently, the ability of improved predictions and recommendations provided by machine learning, deep learning and neural network models to enhance the efficiency and effectiveness of workers and business processes is limited by the availability of data, computing resources and talent necessary for production at scale. For example, supply-chain applications of complex, deep learning models forecasting consumer demand are constrained by the excess computing power required, meaning companies have to weigh internal benefits against cost.

Notwithstanding the broader benefits to society in satisfying customer needs, the brute-force solution of building ever larger data centers to supply more computing power is meeting resistance from governments concerned about the planning implications and climate change; technology providers worried about possible future excess supply; and business users with competing capital allocation requirements. The adoption of AI applications will overcome these barriers, only once the computing burden is addressed in such a way as to permit applications at scale and scope across industries and geographies. Concomitantly, as knowledge sharing continues, software designs advance and intangible assets accumulate, ease of use will improve and AI solutions become more widespread.[21]

For long-term, sustained success, issues of AI transparency, explainability and fairness will all have to be addressed. Consequently, if AI technology is to be adopted at scale, regulatory agreement across nations and, more broadly, accepted social practices, consumer privacy, fair competition and abundant choice all need to be assured.

Barriers to productivity in the Digital Age deployment phase

Several factors of a broader economic, organizational and institutional nature are contributing to the lengthy transformation processes in the current phase of the Digital Age. Addressing these is key to the technology ultimately evolving into a genuine Fourth Industrial Revolution.

Over the past decade, sales have become increasingly concentrated across industries and sectors in the United States and a range of other OECD countries.[22] Other evidence points to rising mark-ups in the United States and Europe.[23] These trends could indicate a potential decline in firm competition, but also reflect a strong concentration of intangibles in the hands of "superstar firms" that are larger and more innovative, with faster productivity growth and a lower share of labor income in revenue.

The existence of such productivity leaders alongside productivity laggards creates persistent productivity differences – even at the sub-industry level – and slows the process of creative destruction. It also points at the slowness with which those lagging behind adopt new digital technologies, often lacking the management skills, worker talent and resources necessary to make the information technology investments required for them to migrate to the productivity frontier.

Although persistently low interest rates over the past decade and a half had the potential to spur investment and productivity growth in the wake of the global financial crisis, they also allowed so-called "zombie" firms to survive, by averting entrepreneurial failure through a reliance on inexpensive capital. This resulted in capital misallocation and sustained product market entry barriers.[24] The notion of secular (or long-term) stagnation, focusing on the occurrence of negative real interest rates, further suggests there has been a lack of appetite by investors, as well as lower capital costs having been a diminishing incentive to invest in physical capital.

These challenges highlight the growing importance of human and intangible capital in facilitating the deployment of new digital technology embedded in tangible capital. Labor quality and worker skills have long been a known determinant of productivity.[25] There are also indications that investment has become far more dependent on the availability of a skilled workforce than on the cost of physical capital.[26] A lack of adaptive leadership skills is another factor holding back the deployment of new technology. For example, Bloom and colleagues have found an enormous dispersion of management practices, with 40 percent of the variation located across plants within the same firm.[27]

Investment in intangible assets, particularly R&D, account for from one-third to one-half of the market value appreciation of tangible assets relative to their replacement value.[28] When the definition of intangibles is expanded beyond R&D to include organizational capital, innovation and transformation, the intangibles contribution to market value increases to about two-thirds. A failure by investors to appreciate the talent required to implement digital technology, and consequently the need for a redistribution of rewards away from capital owners and toward high wage workers – the providers of intangible capital – could be a contributing factor to weak investment growth.

Haskel and Westlake argue that, despite a rapid increase across Western nations, the contribution of intangible capital to continued growth can only be realized through a significant renewal of those key institutions that remain more reminiscent of previous industrial revolutions rather than fit for the current Digital Age.[29] In particular, the combination of spillovers and synergies between different types of intangible capital requires an institutional reset regarding intellectual property, finance, competition and regulation, and spatial distribution. (See GII 2022 Expert Contribution from Peters and Trunschke on the impact of investments in intangible assets on the productivity of German firms.)

Leveraging the opportunities for transformation

Industrial revolutions are typically characterized by a reduction of barriers to transformation resulting from a step change in social and economic activity. Rising inequalities between leading and lagging firms, high versus low-skilled labour, and concentrated urban areas versus left-behind places are a few of the disparities to be overcome in a transition from the installation to the deployment phase. Tackling those differences will be key to realizing the Fourth Industrial Revolution's full benefits. It will involve the diffusion of new digital technologies to productivity laggards, an improvement in the absorption capacity of AI, a redistribution of rewards toward high-skilled labor and intangible capital and away from physical capital, and a broadening of the benefits derived from new technologies so as to include society as a whole.

The economic benefits from digital transformation and AI will be realized when productivity, tangible capital stock and intangible asset growth create multiplier effects. Technology, business process innovation and increased competitiveness induce income gains among businesses and workers that in turn induce further innovation and growth, thereby creating a virtuous cycle. For success to be achieved, and for the benefits to be distributed more equally, skill levels, employment opportunities and the compensation of low-wage workers all need to improve.

How these transitions evolve depends on millions of decisions taken by individuals and firms, as well as on policymakers facilitating or nudging decision-makers in the right direction. The policies and new institutions required for technological, social and economic transformation depend on a combination of "carrots" and "sticks." The carrots focus on policies that facilitate investment in order to encourage new firm entry, better-skilled workers and regenerate places for a reset in growth. The sticks focus on breaking those vested interests that continue to rely on income generated by old technologies. According to Posen "nostalgia privileges a status quo that locks in incumbents' advantages and ignores the difficulties that many people are already suffering."[30]

Transitions often do not happen without an element of frenzy resulting from either a crisis originating within the system (*endogenous*), such as the global financial crisis, or one exacerbated by external events (exogenous), such as the COVID-19 pandemic or global political instability.[31] The current accumulation of multiple short- and long-term crises offers opportunities for change.

The COVID-19 crisis is a case in point. The resultant heightened preference of workers for a hybrid work environment relies on a combination of digital transformation processes, business strategies and government-facilitated change. Increased worker resignation rates – perhaps a reflection of the pandemic's psychological toll – suggests workers at all pay grades are seeking improved opportunities.

Another crisis from which we can leverage an opportunity for transition is a successful transition to a net-zero economy. Critically, this depends upon a combination of digital technologies and energy policies to strengthen computing power in a sustainable way, which in turn ought to improve net-zero behaviors by firms and consumers through the application of AI and deep-learning models.

A final opportunity worth leveraging is the transformation of global supply chains in ways that make them more resilient to disruption at the national level. The challenge is to capture the power of digital technology to integrate domestic activity with global production processes. Such transformation requires substantial financial investment and a business process transformation in which new technologies are deployed and new work opportunities appear. Old ways must be set aside, as networks are rebuilt for future benefit.

While what lies ahead is uncertain and there is no guarantee that the Fourth Industrial Revolution's benefits will be realized, success requires barriers to be addressed, workers and businesses engaged in necessary change, and that policymakers provide much needed leadership to facilitate the transformation.

Notes

1 The term Fourth Industrial Revolution was coined by World Economic Forum founder Klaus Schwab, who argued that the rise of cyber-physical systems meant more than just the rise of another general-purpose technology, but would also bring about large-scale changes to industrial capitalism (Philbeck and Davis, 2019).

2 Cowen, 2011; Bloom *et al.*, 2020.

3 Van Ark *et al.*, 2020.

4 Fleming, 2021

5 Perez, 2002.

6 Harberger, 1998.

7 Fleming, 2021.

8 Fleming, 2021.

9 The main exception to the substitution of capital for labor was during the Second Industrial Revolution's installation period, when technological change was biased toward then abundant unskilled labor.

10 Yellen, 1984.

11 Kahn, 1990; Harter *et al.*, 2003.

12 David, 1998.

13 Chandler, 1998.

14 Gordon, 2016.

15 Chandler, 1990, 1998.

16 Lazonick, 1998, p. 282.

17 Chandler, 1990, 1998.

18 Lazonick, 1998, p. 284.

19 Van Ark, 2016.

20 Zolas *et al.*, 2020.

21 Thompson *et al.*, 2022.

22 Autor *et al.*, 2020; Bajgar *et al.*, 2021.

23 De Loecker and Eeckhout, 2018.

24 Andrews *et al.*, 2017; Banerjee and Ester, 2019.

25 Jorgenson *et al.*, 2019.

26 Crouzet and Eberly, 2020.

27 Bloom *et al.*, 2019.

28 Crouzet and Eberly, 2020.

29 Haskel and Westlake, 2022.

30 Posen, 2021, p. 32.

31 Perez, 2002.

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