European Commission

Joint Research Centre

WORK IN THE DIGITAL ERA:

HOW TECHNOLOGY IS TRANSFORMING WORK AND OCCUPATIONS

2025

E. Fernández-Macías
I. González Vázquez
S. Torrejón Pérez
L. Nurski

EU Science Hub
https://joint-research-centre.ec.europa.eu

JRC141451

EUR 40351

PDF ISBN 978-92-68-28479-7 ISSN 1831-9424 doi:10.2760/0956105 KJ-01-25-327-EN-N

Luxembourg: Publications Office of the European Union, 2025

All images used in this document are AI generated, using OpenAI ChatGPT (DALL·E).

How to cite this report: Fernandez Macias, E., Gonzalez Vazquez, I., Torrejon Perez, S. and Nurski, L., *Work in the Digital Era: How Technology is Transforming Work and Occupations*, Publications Office of the European Union, Luxembourg, 2025, https://data.europa.eu/doi/10.2760/0956105, JRC141451.

TABLE OF CONTENTS

ABSTRACT

This report provides a comprehensive analysis of the impact of digital technologies on work and occupations in Europe, critically reassessing dominant narratives of mass unemployment and job polarisation. The report synthesises work done by the JRC Employment team over the last years. Drawing on a wide range of empirical research, the report introduces an analytical framework distinguishing three main vectors of change: automation, the replacement of labour by machines; digitisation, the increasing use of digital tools in work processes; and platformisation, the use of digital platforms for coordinating work. Contrary to widespread fears, our research finds that the impact of automation, such as industrial robots, on net employment levels in recent decades has been modest and often positive. While specific tasks are automated, this has primarily boosted productivity and led to a reallocation of labour rather than a net destruction of jobs. The most profound transformation stems from digitisation. This process, while enhancing efficiency, has fundamentally altered work organisation by enabling unprecedented levels of standardisation, monitoring, and managerial control. This creates a central paradox: while employment shifts away from routine occupations, work processes within many non-routine professional roles are becoming increasingly routinised and subject to digital control, impacting worker autonomy and job quality. Finally, the report identifies the rise of platformisation, not just in the gig economy, but as a logic of algorithmic management and surveillance extending into traditional workplaces. This trend is reshaping the nature of workplace control across the economy. Analysis of occupational structures reveals that job upgrading, rather than job polarisation, has been the most common pattern of change across the EU, driven largely by the growth of high-skilled service sector jobs. The report concludes that the primary impact of the digital era on work is a qualitative transformation in its nature, focusing on coordination, control, and job quality. The effects of technology are not deterministic; they are strongly mediated by institutional frameworks, with regulation and collective bargaining playing a crucial role in shaping outcomes for workers in the digital age.

EXECUTIVE SUMMARY

The debate surrounding technology's impact on work is centuries old, recurring intensely during times of socio-economic change or rapid technological advancement, such as the Industrial and Digital Revolutions. Remarkably, the core arguments have persisted across time, adapting to specific technologies but revolving around four main themes: machines destroying jobs, degrading work, automating repetitive tasks to liberate workers for higher-skilled roles, or replacing mid-skilled work, creating a polarisation of employment opportunities. So far, these predictions of mass unemployment, degradation, and polarisation have been consistently disproven by actual employment trends.

Amid the latest wave of technological change and economic turbulence, this long-standing debate has regained prominence, fuelled by concerns about computerisation, AI and robotics displacing human labour. In response, the Joint Research Centre of the European Commission launched a research programme in 2017 to investigate these claims and guide EU policymaking. Our research, conducted in collaboration with multiple organisations, has led to a central conclusion: the digital revolution's main impact on work has been in how work is coordinated and controlled rather than in overall employment levels. We have seen evidence of a growing standardisation of tasks and an increased digital coordination of work, rather than widespread job displacement or a significant downgrading or polarisation of the labour market. Our analysis also suggests that the impact of technological change on work and employment is strongly mediated by labour market institutions, with regulation and collective bargaining playing a critical role in shaping the impacts.

Our research departs from the **'Automation, Digitisation and Platformisation' (ADP) framework,** which distinguishes between the technical and social domains of the economy, each with three interconnected levels: technology, the division of labour, and institutions. Within this framework, our research analyses three main vectors of change: automation, referring to the replacement of labour by machines; digitisation, referring to the increasing use of digital tools in work processes; and platformisation, referring to the use of digital platforms to coordinate work. In this report we first revisit the ADP analytical framework, then summarise the JRC's main findings on automation, digitisation, and platformisation respectively, before delving into two key transversal topics: occupational change, and skills and tasks. This approach allows us to systematically analyse how digital technologies are reshaping work and employment in Europe.

JRC research on **automation** challenges the narrative of mass job destruction, finding instead that automation's impact on employment in recent decades has been modest and frequently positive. While automation replaces specific tasks, it also enhances productivity and prompts a reallocation of workers to new roles, generally not leading to a net loss of employment. In manufacturing, robots have boosted productivity and even job creation in related sectors, mainly in high value-added industries. A similar picture is visible in the services sector too where no labour displacement has been identified, but a reconfiguration of tasks and roles is taking place. While the qualitative evidence suggests improvements in safety and ergonomics, it also highlights risks related to increased monitoring and reduced worker autonomy, alongside the standardisation of tasks. Overall, our findings indicate that the primary effects of automation are not on net employment levels, but rather on transforming the nature of work, the coordination of work processes, and working conditions.

In terms of **digitisation of work processes**, our research reveals a complex and often paradoxical picture, highlighting that while digital tools enhance efficiency through information processing and communication, they simultaneously introduce standardisation and centralisation of information. This has resulted in a dual impact on work organisation, with evidence of both routinisation and deroutinisation, increased responsibility alongside reduced autonomy, and expanded communication alongside social isolation. Similarly, in terms of job quality, our research shows that digitisation can lead to upskilling, but it is also associated with task standardisation and often leads to deskilling. Digital technologies also bring flexibility and improve work-life balance for some workers, but at the same time often generate stress and work intensification. Telework itself highlights this paradox, where spatial decentralisation is achieved through standardised processes and centralised digital platforms. In short, the impact of digitisation on work and employment is far from straightforward, revealing the inherently ambivalent nature of these technologies and their effects on human labour, working conditions and workplace control, with the potential for both improvement and deterioration.

As far as the **platformisation of work** is concerned, digital labor platforms have stabilised as a marginal segment of the EU labour market, but we observe that their defining characteristics, notably digital monitoring and algorithmic management, are increasingly permeating traditional workplaces. This 'platformisation of work' is emerging as a key transformation enabled by the digitisation of economic activities. Our research shows that most workers are now using digital devices that are often connected to platforms for management and coordination which become control and monitoring tools. This trend, while potentially enhancing efficiency and productivity, also carries significant risks, particularly with respect to the intensification of work, decreased autonomy, and an increasing incidence of intrusive forms of worker monitoring and surveillance. The risk remains even for countries with strong labour market institutions. We also show that platformisation tends to lead to increasingly standardised and bureaucratised work processes. In this sense, we argue that platformisation reflects a broader trend of increasing centralisation of power and control, and policy action may be needed to steer the development of this new reality.

Our research on **occupational change** reveals a complex landscape that defies simple narratives of job polarisation, showing a wide variety of patterns across countries, regions, and periods. Instead of a universal trend, our studies indicate that 'job upgrading', marked by a greater concentration of employment growth in higher-quality jobs, has been the most common pattern in the EU and globally in recent decades, driven by the tertiarisation of economies, particularly in public services, and to a lesser extent by the growing participation of women in the labour market. However, despite some convergence within countries at the regional level, the study indicates that capital regions concentrate more high-skilled jobs, while peripheral areas tend to be associated to a higher prevalence of low-skilled employment and even job downgrading in some cases. Our research underscores the need for nuanced, context-specific approaches to policy making, rather than one-size-fits-all strategies.

Our work on **tasks and skills** has contributed to the development of comprehensive conceptual frameworks for connecting these two concepts, revealing how digitisation has simultaneously led to increased routine in many work processes, even as tasks shift away from routine occupations. Our taxonomy of tasks highlights the importance of considering not only the content of work (physical, intellectual, social) but also its method (routine, teamwork, or autonomy) and the tools employed (analog or digital), showing that similar jobs within the same occupation can vary significantly in how they are carried out. Using online job advertisement data as a way of identifying skills, our studies reveal a strong demand for digital skills while also highlighting the need for foundational skills, like computer literacy but also so-called 'soft skills'. As skills and tasks are intrinsically related, future research should also explore the optimal bundling of tasks into jobs and teams, both to better design work and stimulate skill development, and to leverage human capabilities in a more effective way.

In summary, after analysing the impact of digital technologies on work and employment, we do not yet see reasons to fear new technologies in this latest historical phase of technological change. Certainly, digital technologies present new challenges, as they drive transformations in the nature of work and how we coordinate it. However, they are not causing mass unemployment or inevitable polarising effects. A proper understanding of the impacts of technological change in the digital era is key to adapting effectively to upcoming challenges, minimising risks while maximising the opportunities they offer. We hope this volume contributes to that end.

ACKNOWLEDGEMENTS

This report synthesises the work of more than 7 years in the Employment team of the JRC, to which many researchers have contributed in the JRC and in other organisations. All of the value of this report comes from the contributions of these researchers. Within the JRC Employment team, we would like to acknowledge the contributions from Annarosa Pesole, Cesira Urzi-Brancati, Margarida Rodrigues, Esperanza Vera-Toscano, Marta Fana, Matteo Sostero, Santo Milasi, Sara Baiocco, Giovanna Mazzeo Ortolani, Amaia Palencia-Esteban, Guillem Vidal and Davide Villani. We benefited also from extensive collaborations with other researchers in the JRC over the years, such as Emilia Gomez Gonzalez, Songul Tolan and David Klenert, among others. Some of the studies synthesised in this report were carried out in collaboration with colleagues from other European and international organisations such as Eurofound, ILO, OECD and EU-OSHA, with John Hurley, Martina Bisello, Sara Riso, Dragos Adascalitei, Uma Rani, Anna Milanez and Maurizio Curtarelli, among others. Finally, we would also like to thank many external academics and researchers who have collaborated with us in the last few years, including Rafael Muñoz de Bustillo Llorente, José-Ignacio Antón, Valeria Cirillo, Dario Guarascio, Matteo Tubiana, Jorge Rodriguez-Menes, Kimberly Goulart, Sudipa Sarkar, Daniel Oesch, Luca Giangregorio, Guendalina Anzolin, Alex Wood, Kirstie Ball, Sally Wright, among many others which can be found in the extensive list of references in this report. Finally, we would like to thank Miguel Cascarano and Carlos Buades for their help with the design of the report, and Mikel Landabaso, Asunción Fernández Carretero and Fernando Hervás for their support.

INTRODUCTION

The debate on the impact of technical change on the nature of work is very old: it started even before the Industrial Revolution.[1] Over the last 200 years, it never disappeared entirely, gaining intensity in periods of socio-economic turmoil (for instance, after the crises of 1929 and 2008) or fast technological change (around the industrial revolution itself, or more recently during the digital revolution). But what is perhaps more remarkable is that the main arguments in this debate have not really changed over the last 200 years, even if they have been adapted to the specific technologies of the time.

We can summarise these recurrent arguments in three big tropes, as follows: 1) machines destroy jobs, and may lead to a workless future (Keynes 1930; Rifkin 1995); 2) machinery (and the division of labour) degrades work and workers (Smith 1776; Braverman 1974); 3) machines replace hard and repetitive work, displacing labour towards better jobs (Solow 1957; Bell 1973). We may add a fourth trope which has been quite popular lately in economic research, combining ideas from the previous three: machines replace mid-skilled work, creating a polarisation of employment opportunities (Autor et al. 2006). These arguments, which were there already in the initial discussions on the impact of the industrial revolution on work (which both Adam Smith and Karl Marx discussed at length), can still be recognised in the most recent discussions about how LLMs (Large Language Models) will transform the labour market.

1 An example from Adam Smith's The Wealth of Nations: "In the progress of the division of labour, the employment of the far greater part of those who live by labour, that is, of the great body of the people, comes to be confined to a few very simple operations, frequently to one or two. But the understandings of the greater part of men are necessarily formed by their ordinary employments. The man whose whole life is spent in performing a few simple operations, of which the effects are perhaps always the same, or very nearly the same, has no occasion to exert his understanding or to exercise his invention in finding out expedients for removing difficulties which never occur. He naturally loses, therefore, the habit of such exertion, and generally becomes as stupid and ignorant as it is possible for a human creature to become" (Smith 1776).

After over two centuries of accelerating technical change impacting work, we certainly have some accumulated evidence to contrast with these arguments. Since the industrial revolution, machines have indeed destroyed some types of jobs, but they have obviously not made human labour disappear. New tasks and jobs have emerged at a similar or faster rate than others have been destroyed by machinery, and the levels of employment are similar or higher in most countries than two hundred years ago. As for the argument that machines (and the division of labour) degrade work and workers, in the long run it did not stand the test of reality either, although for specific periods and countries it may have been the case (for instance, after the first industrial revolution in England, as documented by Engels in 1845; see Engels 1993). Something similar happens with the job polarisation argument, which does apply for some particular countries and periods (such as the US in the 90s), but not as an all-encompassing description of the occupational impact of recent technical change (see contributions to Torrejón Pérez et al. 2025; also Oesch and Piccitto 2019).

At least on a superficial level, the argument that seems more consistent with the last two hundred years of evidence in this respect is the most optimistic one: technical change has eliminated a lot of hard and repetitive work, displacing big amounts of labour towards higher-skilled jobs in services. Of course, this is very simplistic and misses big parts of the story: in particular, it misses broader socio-political trends (such as the creation of the welfare state or the role of unions and labour policies) which interact with technical change and (re)shape its final impact on the nature of work. But at the very broad level of generality at which these arguments are often made, we can say that the predictions of the coming end, degradation and polarisation of work as a result of technical change have so far been greatly exaggerated.

The last couple of decades have been a period of intense technical change and there have been economic turbulences, so this debate has been particularly intense. The dramatic labour market impact of the great recession that started in 2008 provided some material basis for the return of fears of a jobless future. These fears were further fuelled by some very influential studies predicting an imminent large-scale destruction of employment as a result of computerisation (Frey and Osborne 2017, originally 2013), or allegedly documenting an ongoing large-scale replacement of human labour by robots in industry (Acemoglu and Restrepo 2020). As a result, the same tropes of the last 200 years are again anxiously debated: computers, AI and robots are destroying employment en masse (or will very soon); and/or degrading work and workers at a large scale; and/or polarising labour markets; or perhaps they will soon liberate humans from any hard or repetitive work, so that we can focus on the most creative and fulfilling tasks. The most recent and impressive advances in AI, such as LLMs, image and video generation or visual processing continue to fuel these debates.

In this context the Joint Research Centre of the European Commission embarked in 2017 on a research programme to study the implications of recent technological change for the nature of work and inform EU policymaking.

This research programme, which is set to continue in the future, is carried out in close collaboration with DG Employment, Social Affairs and Inclusion, with partner organisations such as Eurofound, Cedefop, EU-OSHA, the International Labour Organisation and OECD, and with the scientific community at large. The analytical framework and key concepts of this research programme were set out in a paper published by Eurofound in 2018, titled "Automation, Digitisation and Platforms. Implications for work and Employment" (Fernández-Macías 2018). In this report we summarise the main findings of this research programme over the last few years, assessing its limitations and gaps in order to take stock and consolidate existing evidence, and propose future lines of research. We contextualise our research in the broader debates on the changing nature of work in the digital age while discussing it from an EU policy perspective.

In a nutshell, our main conclusion is that the main impact of the digital revolution in the world of work over the last two or three decades has been on the modes of coordination and control of work, rather than on employment levels or even on the distribution of employment by skill or job quality. In particular:

- In our research, we did not find a significant effect of computers or robots in terms of overall employment, nor did we see that they have generally downgraded work or dramatically shifted the composition of employment in a polarising way. Instead, what we found is the continuation of secular trends of deindustrialisation/tertiarisation of employment, generally associated with occupational upgrading.

- In contrast, we do observe a very significant impact of these technologies on work organisation, coordination and control, which in turn have important implications for working conditions. These arguments have not played a very prominent role in the debate on the changing nature of work except perhaps within some late proponents of the degradation of work argument (in particular, followers of Braverman and labour process theorists; see Bagnardi and Maccarrone 2023). The changes we find in this respect involve a growing routinisation and standardisation of tasks, and an increasing coordination of work by digital systems (algorithmic management and the platformisation of work). These arguments relate to the Weberian idea of an increasing rationalisation and bureaucratisation of all kinds of human activity (Weber 2015, originally 1922), which can be considerably accelerated and expanded with digital tools.

In the following chapter (2), we will briefly recap and revise the main points of the original analytical framework that underpins our research (Fernández-Macías 2018). The subsequent chapters summarise our main findings on automation (chapter 3), digitisation (chapter 4) and platformisation of work (chapter 5), respectively. Chapters 6 and 7 delve respectively into two key transversal topics: occupational change, and skills and tasks.

THE CONCEPTUAL FRAMEWORK

2.1 The digital revolution in its historical context

In the conceptual framework set out in "Automation, Digitisation and Platforms" (ADP from now on), the digital revolution was defined as "a general acceleration in the pace of technological change in the economy, driven by a massive expansion of our capacity to store, process and communicate information using electronic devices" (Fernández-Macías 2018: 1). To provide some historical context to the present period, this conceptual framework took three key ideas from the work of Schumpeterian economic historians Chris Freeman and Carlota Pérez, who interpret the digital revolution as the fifth of a series of cyclical technological revolutions of the last 200 years (Freeman and Louca 2001; Pérez 2003).[2]

The first key idea borrowed from Freeman and Pérez is that **technical change is not linear or incremental, but punctuated, characterised by bursts of radical innovation followed by periods of consolidation, diffusion and eventually stagnation**. There are technical and socio-economic reasons for this. From a technical perspective, periods of intense technical change tend to occur when a new general-purpose technology (such as the microchip) is introduced. Since new technologies are essentially recombinations of existing ones, the availability of a new general-purpose technology opens up many possibilities for recombination and new applications, which then open up further possibilities and so on, until the range of new possibilities is eventually exhausted (Brian Arthur, 2009). From a socio-economic perspective, the non-linear nature of technical change results from the fact that technologies are embedded in socio-economic structures and new technologies will initially struggle with existing organisational forms, cultural norms, vested interests and institutional settings. Once this socio-economic resistance is broken, the same elements will contribute to the further diffusion and development of the new technologies, accelerating change.

The second key idea is that **all technological revolutions tend to consist of similar cyclical phases**. It all starts with the development of some new technology (such as the microprocessor in the 1970s) with broad applicability and possibilities for recombination. As these possibilities are realised and the technology diffuses throughout the economy, it experiences rapid growth and generates big profits. This attracts investment that provides leverage for further innovation and growth, and funds the installation of new infrastructures necessary to take full advantage of the new tools. This is the installation phase, which is typically associated with a growing speculative frenzy that tends to end in a financial crisis (Pérez 2003). After the crisis, the necessary infrastructures are already in place, as well as the technologies and the skills necessary to use them. We thus enter the deployment phase, when the full socio-economic impact of the new technologies takes place. As the possibilities and applications of the new technologies are slowly depleted, the cycle ends in a period of stagnation until the arrival of some new general-purpose technology kickstarts a new cycle.

Finally, the third key idea borrowed from Freeman and Pérez is that **it should not be taken as a given that a technological revolution will produce value and shared benefits for all society**. Even if technological revolutions imply a radical improvement in the methods and tools of work and thus in the overall productive potential of the economy, they can be highly disruptive

2 The previous technological revolutions were: the initial Industrial Revolution (from around 1770), the steam and railways revolution (from around 1830), the steel, electricity and heaving engineering revolution (from around 1880), and the oil, automobile and mass production revolution (from around 1920). The digital revolution in this framework would have started around the late 1970s, and would be at this point in a rather mature phase (between deployment and stagnation). See Pérez 2003.


LOGISYS
LOGISYS

in broad socio-economic terms and create inequality and suffering. In fact, there are reasons to expect these undesirable social outcomes. First, because the institutional framework, which normally protects society from the externalities created by economic activity, was designed for a socio-economic system now radically changed by the technological revolution. Second, because the large profits, massive investments and financial instability, associated with the installation phase tend to boost inequalities and create social instability. This means that each technological revolution requires a fundamental reshaping of the institutional framework that provides economic stability and social protection.

These ideas can be applied to the digital revolution, as was done in the **ADP framework** (Fernández-Macías 2018: 1-3). The invention of the microprocessor in the early 1970s kickstarted the digital revolution, initially focused on relatively niche products such as videogames and personal computers but eventually diffusing to the whole economy over the following two or three decades. Large profits in the computing industry attracted massive investments, which were used for the development of new products and applications, as well as for the installation of infrastructures (such as the internet) that created further possibilities for the new technologies. As predicted by the theory, this fuelled large financial bubbles which burst in a series of crises at the turn of the century. After these crises the full benefits and applications of digital tools became realised on the basis of broadly available new infrastructures (internet, GPS, mobile networks), skills and know-how. Following this theory, we should be now well into the deployment phase and approaching (if not experiencing) the final stagnation of the current technological cycle.

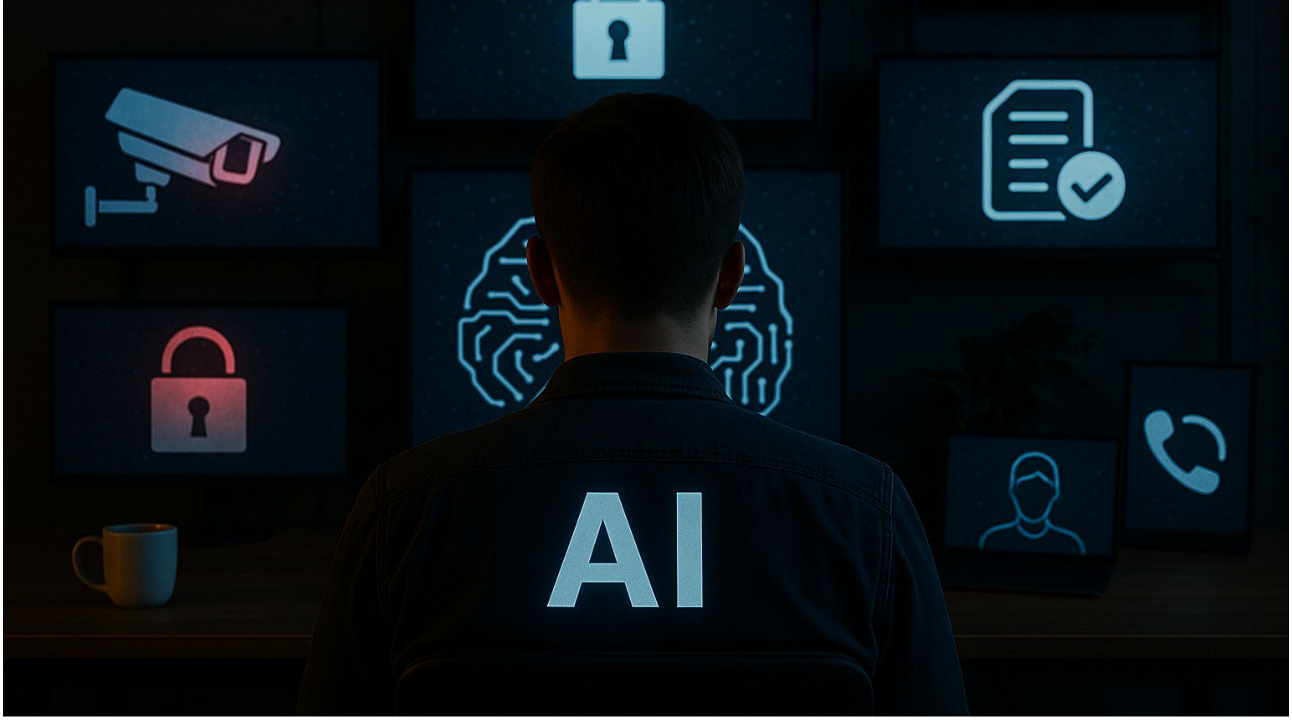
If we are at the end of the cycle of innovation and socio-economic transformation brought about by the Digital Revolution, what comes next? Obviously, there is no way to know, but we can speculate. Many people would argue that the next cycle of innovation will be triggered by AI, an offspring of the digital revolution which has seen enormous progress in the last couple of years. AI is a general-purpose technology whose applicability is enhanced by the ubiquity of digital tools in contemporary societies; it is inherently flexible (almost as the human intelligence it tries to mimic), and in recent years it has been in a learning curve of rapid increases in capabilities and declines in cost. All of these are valid arguments in favour of AI being the trigger of a new technological revolution.

However, there are also reasons to consider AI a late manifestation of the digital revolution, rather than the trigger of a new cycle of technological revolution. Despite its impressive capacity to mimic human cognition, its practical applications so far suggest an incremental and, in some cases, marginal improvement over previous algorithmic systems, often limited to leisure industries and some types of personal services which had already been transformed by the digital revolution. There may be also incipient signs of exhaustion of the current paradigms of AI, with most recent models showing decreasing returns with exponentially increasing costs (Villalobos et al. 2024). In particular, the energy requirements of the current approaches to develop AI seem to grow without any control (Muñoz de Bustillo 2024), which puts an obvious question mark on the economic and environmental sustainability of the whole process.

Another plausible candidate to trigger the next technological revolution is renewable energy, a broad family of interconnected techniques to harness energy from the sun, wind and other renewable sources, and to store it and distribute it in smart and decentralised ways. Again, these techniques are obviously based on general-purpose technologies with broad applicability, with a consistently impressive learning curve over the last few decades (and likely to remain strong for the foreseeable future; see Roser 2020, Schmidt et al 2017). In contrast with AI, these are inherently sustainable technologies from an environmental and increasingly also from a purely economic perspective. Their transformative potential is enormous: among other things, they may decentralise and democratise the generation of energy, making it ubiquitous and potentially almost free.[3]

A final comment on the broad socio-economic significance of the digital revolution concerns its institutional dimension. As previously explained, the cyclical model of Freeman and Perez assumes that technological revolutions tend to have disruptive socio-economic implications, which only result in generalised progress if the institutional framework is adequately transformed. Now that the digital revolution is coming to its end, we can try to assess whether the institutional framework of developed economies has changed sufficiently to be able to minimise its disruptive socio-economic impact and maximise its benefits for all. Although it is obviously too early to tell, from our current perspective we think it has not, or at least not yet.

3 Many people argue that the energy transition is strongly linked to the digital revolution. For instance, renewable energies rely heavily on sophisticated digital control systems (Muñoz de Bustillo 2024), and the decentralised model of energy production and distribution which dominates in renewables has a strong resemblance with the decentralised network model of the early internet.



In Europe, there have been some ambitious attempts at regulating digital technologies with the potential for disruptive socio-economic implications, such as digital labour platforms, algorithms or AI. The European Union has made strides with the GDPR for data protection and the regulation of digital labour platforms. Possible remaining gaps in terms of regulation, implementation and enforcement in areas such as algorithmic management, algorithmic transparency or digital labour rights need to be thoroughly examined. Overall, a holistic assessment of the policy context looking at both opportunities and challenges is warranted. In this context the European Commission has announced for the mandate 2024-2029 a renewed focus on the impact of digitalisation in the world of work, notably through an initiative on algorithmic management and through possible legislation on AI in the workplace, following consultation with social partners.

Outside of Europe, there has been even less policy action to confront the socio-economic impacts of the digital revolution. In liberal democracies such as the US or Australia, there has been limited progress beyond occasional high-profile cases, which often end in settlements or non-binding resolutions rather than systemic reforms. Many regulatory initiatives have stalled due to political polarisation, corporate lobbying and a general reluctance to curtail digital innovation. At the same time, the US has seen some progress e.g. through voluntary codes of conduct, state-level regulation, trade union activism and civil society. Still, this laissez-faire approach has allowed tech giants to exert considerable influence on economic and social structures with minimal oversight, often at the expense of labour rights, data privacy, and market competition.

In partial democracies or authoritarian systems, the institutions have been much more assertive but with rather different goals, aiming primarily at state control and surveillance rather than citizen protection. For instance, in China and Russia, regulatory interventions in digital technologies are extensive, but they are largely designed to support state interests, such as ensuring information control, monitoring citizens, and suppressing dissent. In these contexts, the digital revolution has facilitated extensive state surveillance and data harvesting capabilities, often undermining individual freedoms and democratic norms.

2.2 Domains, levels and components of technical and social change

The starting point of the ADP conceptual framework is the distinction of two domains in economic processes: the technical and the social (Fernández-Macías 2018: 5-7). On the one hand, we can see the economy as a technical process of transforming inputs into outputs. From this perspective, technology can be defined as the tools and methods used in this process. On the other hand, we can see the economy as the social process of collaboration between different people to produce the goods and services necessary to sustain themselves.

Both domains (the technical and the social) are analytically distinct but practically intertwined and deeply integrated in each other. On the one hand, people are obviously an integral part of any technical production process, providing energy, skill, ingenuity and agency. Social coordination mechanisms such as the division of labour or institutions can, in fact, be considered as 'social technologies'. On the other hand, technologies are created and used by people, and therefore they will be shaped by people's interests, values and norms. Simultaneously, these technologies will also alter and reshape social relations and social coordination mechanisms. In short, the two domains are inextricably integrated and continuously influence and reshape each other.

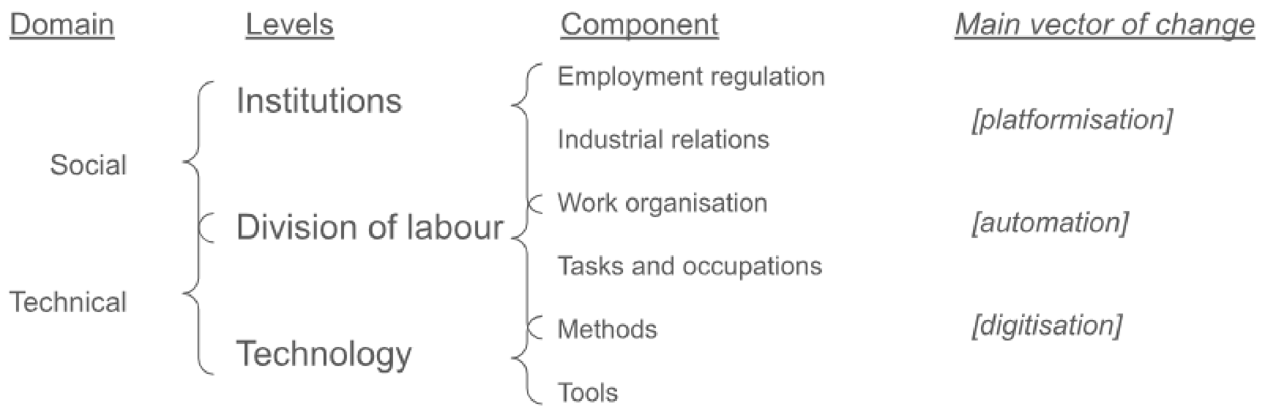
As can be seen in Figure 1 below, this dual distinction – of technical versus social domains of the economy – can be further decomposed in three levels: technology, the division of labour and institutions. Technology refers to the tools and methods used in production and corresponds unambiguously with the technical domain. Institutions, on the other hand, refer to the enduring and socially constructed mechanisms that coordinate economic interactions, corresponding unambiguously with the social domain. But there is a third element, the division of labour, with a very peculiar position in this framework because it is both in the technical domain (as it reflects the technical specialisation of labour input into the economic process) and in the social domain (as it is a key mechanism for the social coordination of collaborative economic activity). In other words, the division of labour (and its subcomponents: tasks and occupations, and work organisation) plays a pivotal role between the technical and the social domains in our framework, and as such it has played a central position in most of our analysis of the changing nature of work in the digital age.

As shown in Figure 1, these three levels are further disaggregated into a series of components, which roughly correspond with research topics that we have covered in this research programme over the years. At the lowest level of the technical-social continuum (at the most 'technical' extreme), we have included the tools and methods of production. Above, we differentiate three components of the division of labour (from more technical to more social), namely: methods, tasks and occupations, and work organisation. Finally, the institutional level (the most 'social' extreme) is differentiated in three components, again from more technical to more social: work organisation, industrial relations and employment regulation.

As the reader has surely noticed, two of the components are hybrid, corresponding to two levels simultaneously: methods are both a component of technology and of the division of labour, while work organisation is part of the division of labour but it can also be considered an institutional feature. In any case, these demarcations are mostly intended for analytical purposes, to help locate and contextualise the different elements of our framework.

Figure 1 also shows the link between the domains, levels and components of our framework and the three vectors of change that we will discuss in the next section. Here the demarcations are less precise, because each of the vectors (automation, digitisation and platformisation) can affect all domains, levels and components simultaneously (again, all elements are interconnected, and any differentiation is more analytical than practical). However, it is useful to briefly mention where they would be broadly located in the overall framework shown in Figure 1. Digitisation (the increasing use of digital tools in work contexts) is most directly linked to the technical domain, corresponding with the technology level and with the methods and tools components. Automation (the replacement of labour by machines) is mostly related with the division of labour, directly affecting both work organisation and the distribution of labour input by tasks and occupations. Finally, platformisation (the use of digital platforms to coordinate work) is mostly a phenomenon of the social domain, directly affecting the institutional framework of labour (outside and within productive organisations). In the next section, we develop these ideas in more detail

Figure 1 Domains, levels and components of ADP conceptual framework



Box 1: Attributes of the digital economy

In the ADP paper, there was a section discussing some peculiarities of the digital revolution that were particularly disruptive, with potential implications for work and employment (Fernández-Macías 2018: 9-13). In our research on digitalisation and the changing nature of work in Europe over the last few years, we often observed these peculiarities to play an important role, so it is worth reviewing them here briefly.

A first important peculiarity of the digital economy is that the possibility of controlling machines and processes with algorithms (rather than using mechanical control systems) increases considerably the flexibility of production. This is something that we observed again and again, particularly in qualitative research on the impact of digital technologies at the workplace level: these systems allow a better control but importantly also more flexibility. Recent advances in AI promise to extend this flexibility much further. If algorithms allow to control processes on the basis of predefined rules, AI systems potentially allow to control processes on the basis of broadly defined goals. A paradoxical effect of this improvement in flexibility and control with digital systems is that it tends to centralise power in productive structures, both within and across firms, as we will see in this report.

A second important peculiarity is the ubiquity of information. Again, this has been a recurrent finding in our research in recent years: digitisation tends to convert everything into information that can be stored, processed and communicated. This not only alters the nature of work as discussed in this report, but also the nature of economic activity. In particular, the boundaries between markets and firms tend to be redrawn. On the one hand, this ubiquity of information facilitates subcontracting and fragmentation (with perfect information, it is often cheaper to buy services in the market rather than integrate them into the organisation). On the other hand, it reinforces hierarchies and centralised control (with some companies acting as information nodes absorbing an increasing amount of power across networks of clients, suppliers and subcontractors).

Third, digital platforms tend to become increasingly central and powerful in the domains where they operate, because of particular attributes of digital goods and networks. Zero marginal costs for digital goods allow platforms to provide them freely in exchange for users' information: in practice, this gives platforms powers of data collection, monitoring and even control of their users, not dissimilar to those observed in digital labour platforms and platformised companies with respect to workers. These mechanisms are reinforced by network effects, which are pushing towards historically unprecedented levels of market concentration in the digital economy.

2.3 The three vectors framework revisited

After explaining the key concepts (see section 2.2) and discussing some key attributes of the digital economy (see Box 1), the ADP framework discussed some initial assumptions and preliminary considerations on the potential impact of digital technologies on work and employment. In the framework these elements are clustered into three main "vectors of change" (automation, digitisation and platformisation, which give the title to the research programme). Each of these three vectors correspond to "broad categories of combined applications of digital technologies in economic processes, with different implications for work and employment" (Fernández-Macías 2018).

These vectors are prototypical phenomena of the mature phase of the digital revolution: they presuppose a certain degree of maturity and diffusion of digital technologies, skills and infrastructures, and involve the type of profound socio-economic transformation that characterises the advanced phase of technological revolutions. The three vectors were identified after a detailed review of the literature in this area (see Peruffo 2017; Peruffo and Schmidlechner 2017; Schmidlechner and Peruffo 2017), which also served as a basis for some considerations and hypotheses for each of them (Fernández-Macías 2018: 15-21).

Table 1 presents a summary of the three vectors framework, covering their definitions and the initial considerations presented in the ADP paper, as well as a very succinct summary of our findings in our research on these topics over the last few years. In subsequent chapters of this report, we discuss more in detail our findings for each of the vectors of change and their socio-economic and policy implications: here we will only define them broadly and outline some of the key findings for each of them over the last few years.

Automation

The first vector of change of work and employment in the digital age is **automation**, defined as **the replacement of labour input by machine input for some tasks within production and distribution processes**. With respect to our conceptual framework, automation mostly concerns the intermediate level of the division of labour. It directly reshapes the distribution of labour input across tasks and occupations, while simultaneously transforming production processes. Indirectly, it also affects the methods of work and work organisation. The most widely discussed effects of automation on work and employment are, on the one hand, the destruction of employment as such (technological unemployment), and on the other the existence of some sort of systematic bias in such destruction, most commonly towards low-skilled employment (the hypothesis known as skills-biased technological change) or towards routine employment (routine-biased technical change). These effects would create either technological unemployment or polarising trends in the labour market.

In stark contrast with the abundant (and sometimes dramatic) literature on this topic, we found generally small and positive rather than negative effects of automation technologies on employment (chapter 3). Over the last two or three decades, as European workplaces were being transformed by the digital revolution and computers replaced a significant amount of routine administrative tasks, overall employment has been generally resilient and growing (beyond the usual short-term cyclical fluctuations). Occupational structures have changed, but those changes have been slow and incremental rather than drastic or revolutionary (chapter 6), and the nature of those changes has tended to be positive. The most common pattern of occupational change in European countries in recent decades has been one of occupational upgrading (with a consistent expansion of higher paid occupational groups). The few cases of job polarisation or occupational downgrading seemed to be more linked to policy-driven processes of labour market deregulation than to technological change.

> “In Europe, industrial robots are a very specialised technology which has contributed significantly to productivity growth and to the resilience of some high value-added industries in recent years”

We also researched the canonical example of automation, the replacement of human operators by robots in industry (chapter 3): even in this case, we found a continuation of secular trends rather than any significant disruption over the last few decades, and a much more positive story than portrayed by the media. Our research shows that in Europe, industrial robots are a very specialised technology which has contributed significantly to productivity growth and to the resilience (even in terms of employment) of some high value-added industries in recent years (in particular, car manufacturing, plastics and metals). In short, we found no evidence of an acceleration of previous automation trends: whatever labour input was replaced in this period was more than compensated by the creation of new jobs (often of better quality) elsewhere.

Digitisation

The second vector of change in our framework is **digitisation**. This is defined as the use of sensors and rendering devices to translate information from physical to digital and vice versa. Arguably, this vector could encompass the entire digital revolution, which is ultimately about the broad socio-economic effects of digitising everything. However, we specifically refer to the direct impact on workers of the increasing use of digital devices in production processes. If automation mostly operates at the level of the division of labour, altering the distribution of employment across tasks and occupations, digitisation mostly operates at the technological level, transforming the technical foundations of work processes.

In the early stages of the digital revolution, digitisation mainly concerned tasks and activities which involved the processing of information. But as the digital revolution matured, and the capabilities of digital devices expanded while their costs plummeted, essentially all aspects of work became increasingly digitised. The Internet of Things and Industry 4.0 are examples of all-encompassing digital systems, which convert almost everything that exists or happens in the workplace into usable information. This information is centralised and processed by management, which can achieve previously impossible levels of control. The digitisation of work processes directly affects working conditions because it transforms the technical nature of work process, and work organisation because it boosts the capacity of management to monitor and control the activity of workers.

The most discussed effects of digitisation in the literature are the increased levels of monitoring and surveillance at work, the associated reduction in workers' autonomy, and the blurring of boundaries between work and life domains. In our research over the last few years (chapter 4), we did observe these effects of digitisation of work processes, and many others. Without any doubt, this "vector of change" has been the most consequential of the three.

Over the last two or three decades, digital tools went from specialised devices mostly used for administrative and information processing tasks, to pervasive elements of all kinds of work environments and processes. A big proportion of workers spend a significant amount of their working hours in front of computer screens, conducting most of their work tasks in a digital environment. Nowadays even those workers who interact with material objects or people who are physically present are - in most cases - being observed, monitored or tracked through some kind of digital device. Digital cameras and all kinds of sensors, cards and mobility trackers, connected chips attached to materials, goods, shelves, etc. All of these digital devices generate a continuous flow of information which is centralised and processed in servers under managerial control.

This profound and pervasive transformation of the technical nature of work has important implications for workers, in particular through the intensification of work effort and pace. This is a phenomenon that we (and other researchers) have consistently found to be correlated with the digitisation of work. On the one hand, this results from the increased pressure on workers from the digital monitoring and control systems. On the other hand, this intensification of work is associated with the increasing standardisation and bureaucratisation of work which is also an (unintended) consequence of the digitisation of work.

The same digital technologies that increase the efficiency and intensity of work processes also tend to create administrative clutter. These two contradictory effects result from the massively increased capacity of collecting and processing information on work processes. The increased possibilities of control can be used for enhancing efficiency, but also for controlling work to an excessive and counterproductive extent. These two effects are contradictory with respect to productivity, which may to some extent explain Solow´s paradox[4]: the surprisingly small effect of digital technologies on productivity may result from productivity gains being offset by increasing administrative burden. However, in terms of the effect on workers, both effects go in the same (negative) direction of intensifying work effort and pace, as well as reducing the autonomy of workers in performing their jobs.

Platformisation

Finally, the third vector of change in our framework is **platformisation**, defined as the increasing use of digital networks to coordinate work in an algorithmic way. The digital platform is the most common form of coordinating transactions in digital networks, and as economic activity becomes increasingly digitised, it tends to be also increasingly platformised. The main level at which this vector operates is the institutional, because the platform is a particular (new and digital) form of social coordination for interactions at work. Thus, platformisation transforms directly the nature of employment and work relations, the social structure of production.

Our research of this vector of change of the digital revolution (chapter 5) started by looking specifically at work in digital labour platforms (DLPs), trying to better define and quantify this phenomenon in Europe and assess its implications for workers. We largely corroborated and expanded the findings from previous literature, confirming that many platform workers face precarious and socially isolated conditions of work, with unclear employment rights

4 "You can see the computer age everywhere but in the productivity statistics" (Solow 1987).

in the majority of EU Member States. However, contrasting with the initial assumption that platform work was a rising phenomenon, we observed a stabilisation of the phenomenon across most of Europe between 1 and 2% of total employment, consolidating DLPs as a marginal form of work.

Simultaneous to this stabilisation of DLPs we observed an extension of some of their key characteristics to regular employment settings. This trend, which we called 'platformisation of work' (Fernández-Macías et al. 2023), is expanding the implications of this vector of change well beyond digital labour platforms. The big push in the platformisation of all kinds of work came during the COVID-19 pandemic. The need to coordinate millions of remote workers and to enforce social distancing, in a context of urgency that minimised previous privacy concerns, led to the massive use of centralised digital platforms for work collaboration and coordination. When the pandemic was over, these platforms remained in use and have been further developed since. These are ostensibly digital platforms which at least provide channels for communication and collaboration in work (as Microsoft Teams, Google Docs or Slack), but which in all cases also incorporate functions of digital monitoring and algorithmic management of work processes. Some of the effects on work which we had previously observed for DLPs (intensification of work, reduction in autonomy, social isolation, increasing and often intrusive forms of monitoring and control) are therefore being extended to these 'platformised' regular work environments.

The broad consequences of automation, digitisation and platformisation

Although automation, digitisation, and platformisation are the primary drivers of change in the digital age, these and other transformations are having a broad impact beyond the effects previously mentioned. For instance, they contribute to transforming work, creating new roles, and driving uneven growth across occupations, thereby reshaping occupational structures. Moreover, they directly influence the tasks performed in the workplace and the skills required to perform them and succeed in the labour market. Therefore, in addition to the chapters addressing the vectors of change outlined in Table 1, we also include two additional chapters: Chapter 6, which examines recent trends in occupational change, and Chapter 7, which explores changes in tasks and skills.

Table 1. The three vectors framework revisited

	Definition	Scope of effect	Nature of effect according to the literature	Our assessment of the effect
Automation	Replacement of labour input by machine input for some tasks within production and distribution processes	• Main level: Division of labour • Transforms production processes, altering the distribution of labour input across tasks. • Affects directly the division of labour and working conditions	• Skill-biased or routine-biased technical change • Technological unemployment • Job polarisation (or occupational upgrading)	• Small, generally positive impact on employment; • Slow and incremental process of occupational upgrading; • Little effect on manual tasks (already automated!); • Some effect on administrative tasks.
Digitisation	Use of sensors and rendering devices to translate information from physical to digital and vice versa	• Main level: Technology • Transforms nature of production and work, converting almost everything into usable information. • Affects working conditions, but also work organisation and more	• Increased monitoring and surveillance • Reduced autonomy • Blurring boundaries between work and life	• Large and pervasive effects; • Intensification of work; • Reduced worker autonomy, increased bureaucratic (digital) control; • Standardisation (routinisation) of intellectual and social tasks.
Platformisation	Use of digital networks to coordinate work in an algorithmic way	• Main level: Institutions • Transforms the nature of employment relations, the social structure of production. • Affects directly employment conditions and industrial relations, but also work organisation.	• Digital Labour Platforms (DLPs): precarious work, isolation, unclear employment rights. • Automation of middle management functions. • Work intensification, reduced autonomy.	• Medium but expanding effect; • DLPs stabilised as a marginal phenomenon; • Platformisation of regular work, similar to DLPs (intensification, reduced autonomy, digital monitoring, algorithmic management), may converge in the future; • Probably enhanced by AI.

THE AUTOMATION OF WORK

Automation involves substituting human labour with machine input for specific tasks within production and distribution processes. Technologies do not automate entire occupations or jobs; instead, automation usually operates at the task level. In this context, jobs or occupations can be understood as bundles of tasks. There is no worker performing one single task, irrespective of the skill level of the job, but rather combinations that define the purpose and characteristics of the job. This implies that machines can replace labour for particular tasks, but rarely for an entire job or occupation. This distinction makes the task approach (see Chapter 7; Bisello et al 2021; Fernández-Macías et al. 2022; Fana et al. 2023) especially valuable and widely used in the specialised literature.

A central question driving studies in this field is whether automation technologies primarily complement human labour or have the potential to fully substitute it. While direct substitution of human labour by machines can occur, automation's impact on employment is often indirect. For example, machines enhance productivity, reducing the amount of labour required per unit of output.

By targeting specific tasks and work activities, automation alters the structure of labour demand and reshapes employment patterns. However, its implications extend beyond shifts in labour demand. Automation is intricately linked to the organisation of work and the division of labour, directly influencing how tasks are socially coordinated within production processes and how firms and institutions structure and distribute functions. In this regard, we do know, for instance, that the standardisation of tasks often precedes automation, shaping both working conditions and power dynamics in the workplace (Braverman, 1974). Standardisation simplifies and unifies tasks, thereby facilitating the replacement of human labour with machinery.

On the other hand, automation affects the extent to which work processes depend on human input, ultimately influencing how labour is allocated across occupations and sectors. For example, in the automotive industry, robots have replaced humans in repetitive tasks such as welding and painting, significantly reducing human labour input in these processes. However, humans continue to play a vital role in more complex, less standardised tasks, such as quality control or assembly line adjustments.[5] Similarly, in logistics, automated sorting systems in warehouses have reduced the need for manual sorting while creating new roles in robot maintenance and system management.

In summary, automation intersects with broader socio-economic issues, including job quality and occupational change. However, this chapter focuses specifically on the direct impacts of automation on employment, only touching these other issues secondarily. Other chapters (notably, chapters 4 and 7) cover those other issues more in depth.

3.1 The impact of industrial robots on employment and productivity

Some jobs are at risk of being replaced by machines, and others are being transformed by the adoption of new technologies and procedures, while entirely new roles are emerging. In this section we synthesise our recent research on the effects of industrial robots – a widely adopted form of automation technology in EU industries – on the EU economy. This section has four objectives: first, to describe what industrial robots are how they are distributed within Europe; second, to evaluate the net impact of industrial robots on employment (do they lead to job losses or job

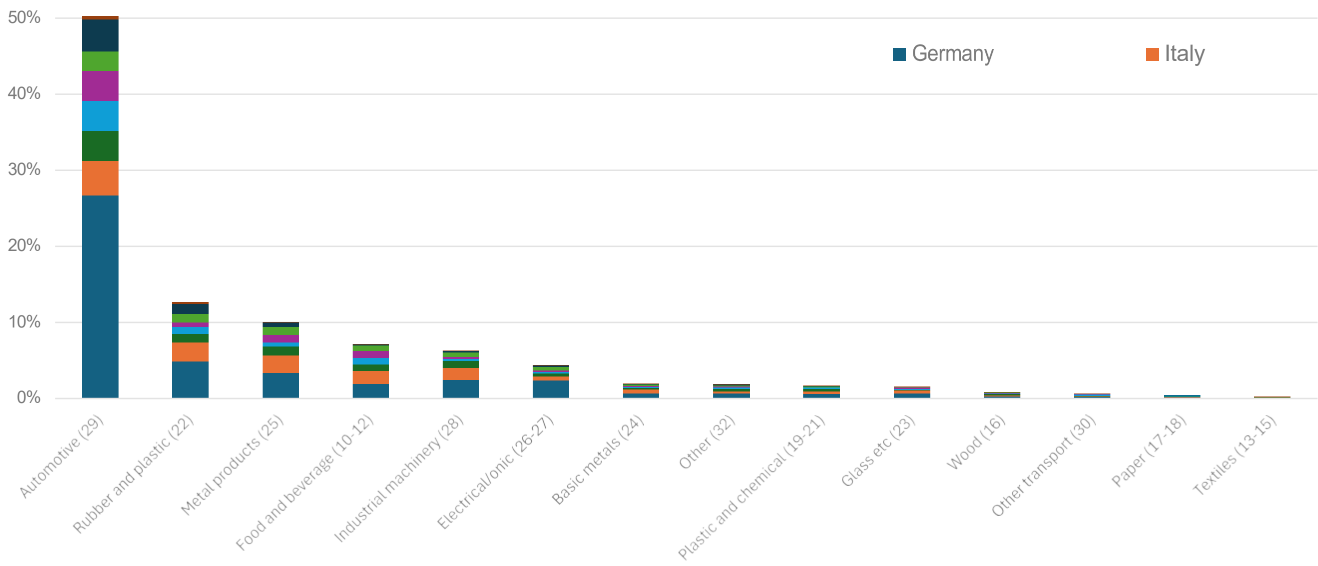
5 For more details on the impact of automation in the automotive sector, see section 3.2.

creation?); third, to analyse their contribution to productivity growth; and forth, to examine their contribution to occupational change.

Characteristics, applications and distribution of industrial robots in Europe

Industrial robots have been around since the mid-20th century, but their deployment intensified from the nineties: the number of robots in the EU-28 in 2016 was four times higher than in 1995. However, the scope of current industrial robots in terms of applications is still limited: their use is concentrated in repetitive manual tasks such as handling, welding and moulding. Furthermore, half of all EU robots are installed in the automotive sector, and 73% of all robots are deployed in only three sectors: automotive, rubber and plastic and metal products (see Figure 2).

Figure 2. Distribution of industrial robot stocks by sector and country, EU (2016).



Source: Fernández-Macías et al. (2021), with data from the International Federation of Robots.

Industrial robot use is also concentrated in few countries, especially Germany, but also Italy and France.[6] As a result, 27% of all European robots are concentrated in German car manufacturing, a sector that accounts for less than 1% of total employment in the EU today (Fernández-Macías et al. 2021). This concentration limits significantly the potential role that robots may have played in recent economic and employment trends in Europe, as detailed below.

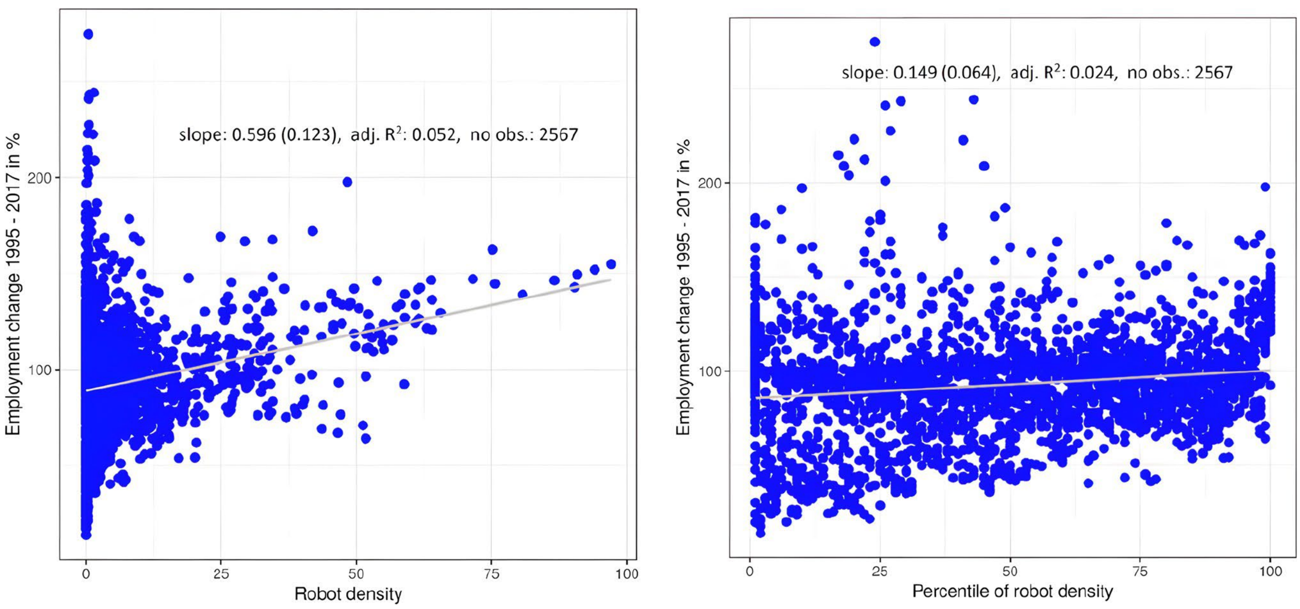
Do robots really destroy jobs?

Industrial robots have been widely deployed during a period when many European countries were experiencing deindustrialisation. As a result, robots have often been blamed for the job losses associated with this process. Reflecting these concerns, a special issue of the Eurobarometer (European Commission 2017) revealed that nearly three-quarters of Europeans believed the use of robots and artificial intelligence would result in more jobs disappearing than being created (74%). Similarly, almost as many respondents agreed that robots and artificial intelligence 'steal' people's jobs (72%). This suggests that there is a significant 'automation anxiety' across Europe.

6 Outside Europe, in 2022, robot density was highest in the Republic of Korea and Singapore, with Asia, on average, outperforming both Europe and the Americas on this indicator. However, in terms of annual robot installations that year, China led globally, followed by Japan and the United States. More info in: https://ifr.org/wr-industrial-robots/

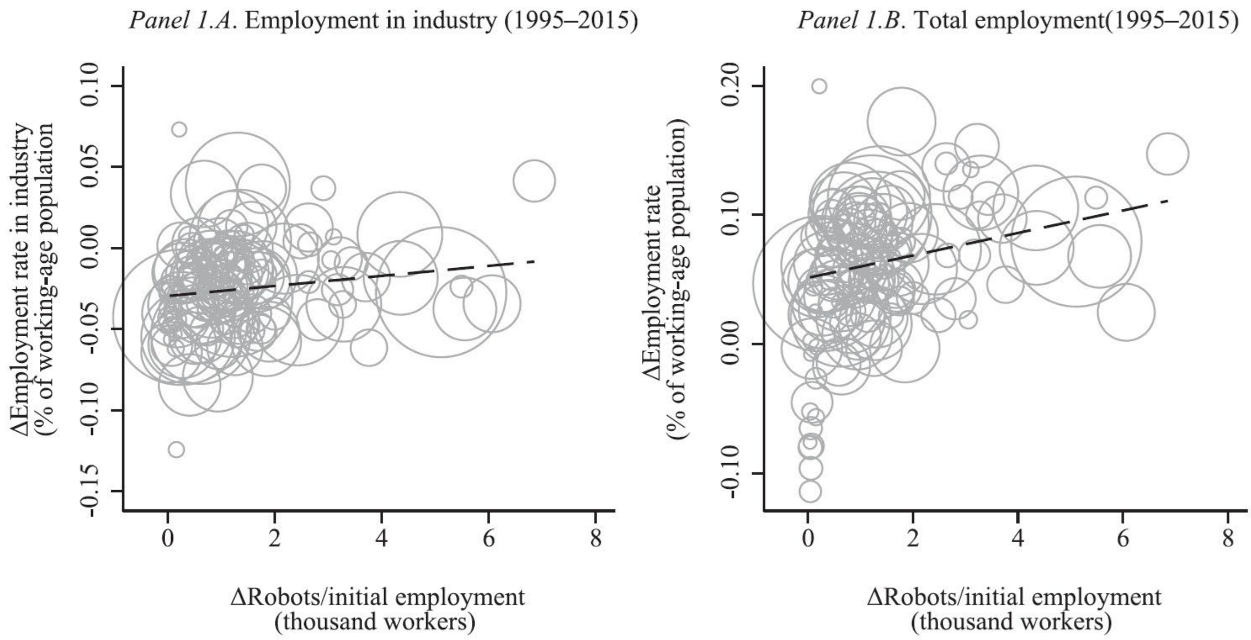
But what does our own evidence suggest? Is there truly a negative relationship between robot use and employment creation in Europe? In Klenert et al. (2022), we suggest the opposite: we find a small but significant positive association between robot use and total employment during the period 1995–2017 (see Figure 3). This suggests that industries adopting robots have, so far, been comparatively more resilient to the long-term decline in EU manufacturing employment. These results contrast with earlier studies and challenge the widespread notion that robots inevitably replace workers.

Figure 3. Robot density and change in total employment (1995–2017)



Source: Klenert et al. (2022), World Robotics database and EU-LFS.

Figure 4. Correlation between changes in employment and in robot exposure by region (1995-2015)



Source: Antón et al. (2022), IFR (2018), EU-LFS and ECHP.

“In short, robots have not had a disruptive impact in terms of employment in recent decades in Europe. The evidence we describe does not concur with the popular narrative of robots destroying jobs at a large scale.”

These findings align with those obtained by Antón et al. (2022),[7] who also confirm a positive association between regional robot exposure[8] and total employment during a similar period, specifically from 1995 to 2015 (see Figure 4). The regional analysis of Antón et al. (2022) add nuance to the discussion, as the effects vary over time: according to their estimates, the impact is small and negative during 1995–2005 but shifts to a positive effect during 2005–2015 across most model specifications and assumptions. These findings reinforce the notion that industrial robots are not causing a disruptive effect on the labour market. Instead, the impact of robot adoption on employment tends to be modest and varies across timeframes. These results have been confirmed by many different external studies in recent years (for an excellent and thorough meta-analysis, see Guarascio et al. 2024).

In short, robots have not had a disruptive impact in terms of employment in recent decades in Europe. The evidence we describe does not concur with the popular narrative of robots destroying jobs at a large scale. However, it should not be understood as proof that robot adoption is causally linked to employment growth. Rather, it invites to be sceptical with claims about the disruptive effect of this technology in the labour market.

Do industrial robots foster job polarisation?

A significant portion of the literature on occupational change, particularly in economics, identifies technology as one of the primary forces reshaping employment structures. While the sociological strand of the literature has emphasised more the influence of various factors on employment dynamics (institutions, demographics, and so on), most researchers have long regarded technology as the most critical driver. However, many studies address technology in broad terms rather than examining specific innovations and often fail to empirically test their impacts.

---

7 While Klenert et al. (2022) study the effect of robots on employment from a sector perspective, Antón et al. (2022) address the same question by looking at the regional distribution of robots.

8 Robot exposure measures how exposed has a given region being to the expansion of robots in recent years, on the basis of its distribution of employment in 1995 and the evolution of robot stocks between 1995 and 2016. For instance, if a region had a lot of employment in car manufacturing, the sector where more robots were installed in this period, it will have a high level of robot exposure in our measure.

Instead, they frequently infer or simply assume that observed changes may be attributed to technological advancements. In this context, our research contributed to the debate by providing empirical estimates of the effects of one specific innovation (industrial robots) on employment structures.

Klenert et al. (2022) explore this relationship by examining the link between industrial robot use and low-skilled employment, finding no evidence that robots reduce the share of low-skilled workers across Europe. These findings are complemented by the regional evidence provided by Antón et al. (2022). According to their estimates, robots produced no job polarisation in the period 1995-2015. On the contrary, their effect seemed to be the complete opposite: according to this study, robots contributed to mid-upgrading, i.e. robots tended to have a slightly more pronounced positive effect on employment for middle-wage jobs.

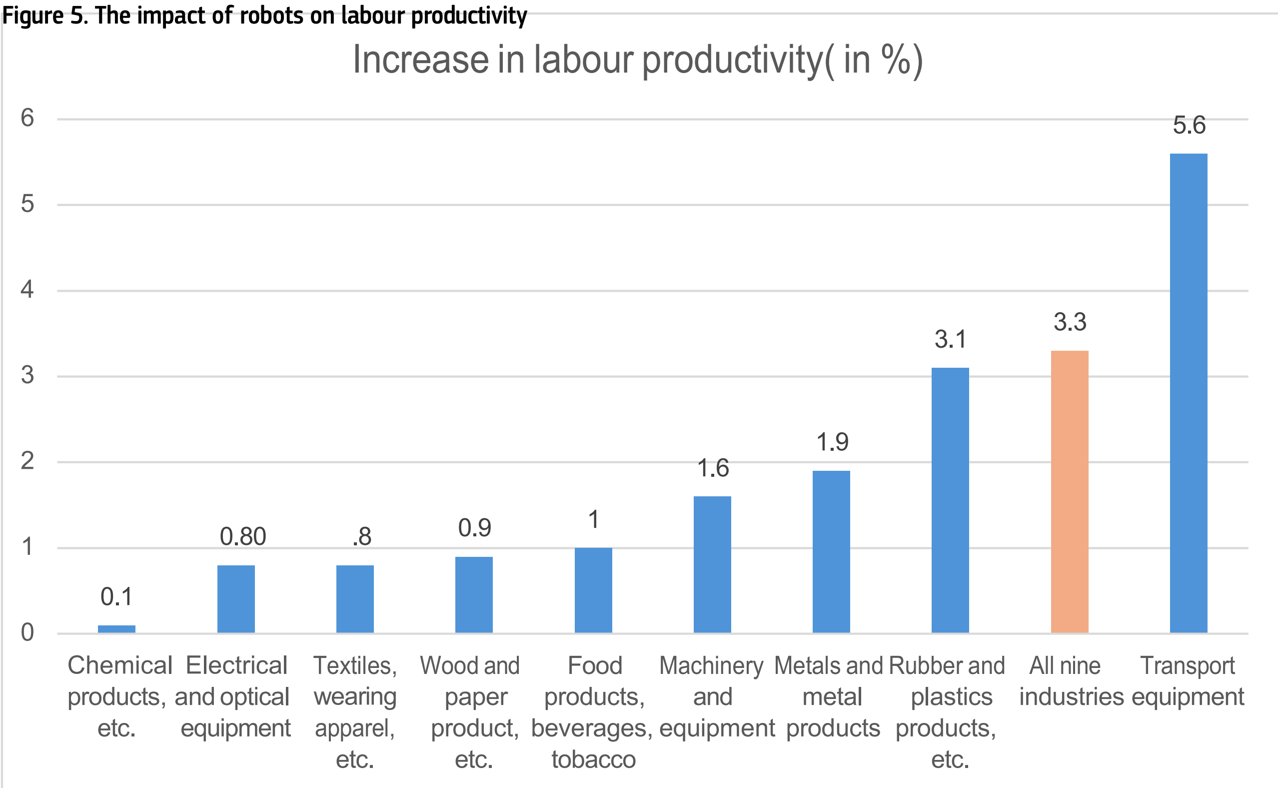
Antón et al. (2022) also analyse the effects on the employment structure in different decades (1995-2005 and 2005-2015), and for all analysed subperiods the statistical significance depends strongly on the model specifications. Consequently, these results should be interpreted with additional caution. While more research is still needed to accumulate evidence and fill the remaining knowledge gaps, for the moment one can say that these results seriously question the role of industrial robots as a key driver of job polarisation in recent decades. Again, we found no evidence of the alleged negative implications of robots on the labour market, not even when looking at their effect on low-skilled employment or their impact in terms of job polarisation.

While understanding how specific technologies affect employment change is valuable, as stated above, patterns of occupational change are ultimately shaped by a variety of mechanisms. These range from those with shared impacts across countries, such as technological advancements and changes in international trade, to country-specific factors, including institutional settings, migration dynamics, changes in organizational culture, and more. In chapter 6, we discuss these issues in the context of a more thorough overview of recent European and global trends in occupational change.

Do industrial robots boost labour productivity?

Technological change is expected to boost productivity by directly increasing total factor productivity. Any increase in value added that is not explained by growth in production factors (i.e., capital and labour) can be attributed to

Figure 5. The impact of robots on labour productivity



Source: Jungmittag & Pesole (2019) with data from IFR (2017) and EUKLEMS (2017)
Note: The figure displays the impact of a one standard deviation increase of robots (per 1 million Euro no-ICT capital input) on labour productivity

technological progress. However, not every investment necessarily leads to productivity growth. This is what some economists observed during the 1990s, when a sharp rise in Information and Communication Technology (ICT) investment did not correspond with an increase in productivity growth, leading to what is known as the "Solow paradox" (see footnote 4). Have industrial robots created a similar paradox? Or, on the contrary, is industrial robot adoption associated with an increase in labour productivity?

According to Jungmittag and Pesole (2019), the intensified use of robots between 1993 and 2015 contributed to the growth of labour productivity in the European industry. They found that an increase of one standard deviation[9] in the relative number of robots compared to non-ICT capital input would result in a 3.3% increase in labour productivity. The authors conducted the same analysis for different sub-periods and observed that the positive impact of robot use on productivity increased from 1995-2007 to 2008-2015. These results could suggest that robots need to reach a certain critical mass to achieve their full beneficial impact on labour productivity, or that knowledge is cumulative, which translates into both robots becoming more effective over time, and greater know-how on their successful implementation in workplaces. However, the exact reason why their positive impact on productivity has increased over time in Europe remains unanswered from a causal perspective.

The same study also provides estimates by sector (see Figure 5), revealing that the positive effect of robots on productivity varies considerably across industries. It is most pronounced in industries with the highest average robot density, as those identified earlier in Figure 2, such as transport equipment, rubber and plastic products, metals and metal products, and machinery and equipment. In contrast, the effect is minimal (equal to or below 1%) in other sub-sectors.

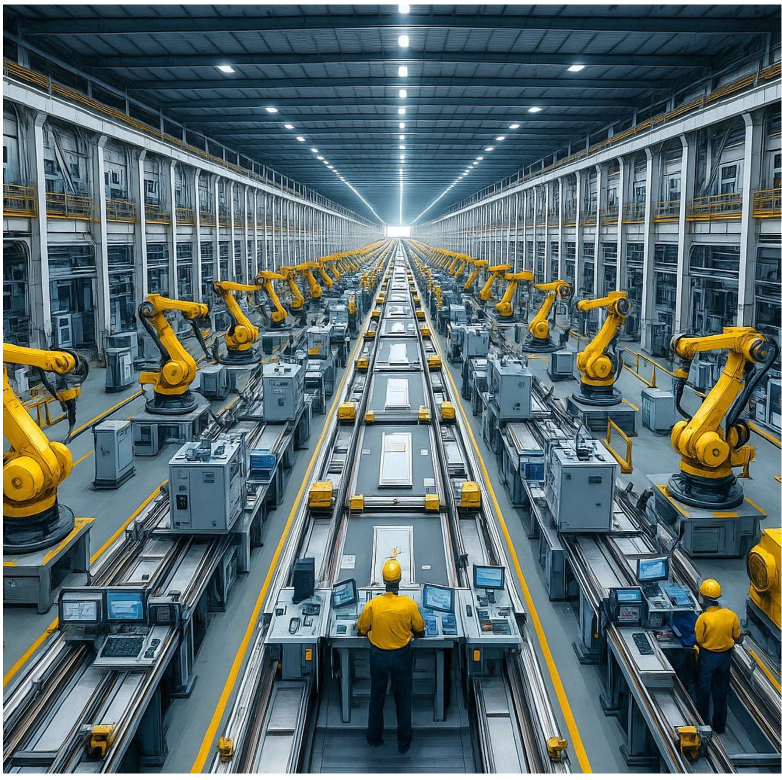
The results of Jungmittag and Pesole (2019) align with previous studies that also establish a significant positive effect of robot adoption on productivity (see for instance Graetz and Michaels 2018). Consequently, this evidence complements earlier findings focused on the impact of robots on employment and reinforces the notion that robots have an overall positive impact on both the labour market and the economy.

In this context, and given the convergence in robot density across manufacturing industries from 2005 to 2015 -unlike from 1995 to 2005 (Jungmittag, 2020) - it is reasonable to expect that this trend may have also promoted some convergence in productivity across those industries. This reinforces the potential positive impacts of robot adoption on European industry and offers valuable insights for the design of industrial and cohesion policies for EU countries and regions.

In short: a positive but limited impact of robots on employment

Building on previous findings, the impact of industrial robot use on employment and productivity appears to be positive. However, the strength of the associations found tends to be modest and estimates are sensitive to different methodological approaches, warranting cautious interpretation. Consequently, we do not anticipate robots to cause disruptive effects on employment.

Moreover, the evidence discussed thus far pertains primarily to the impact of robots in manufacturing, a sector with limited weight in the European context (representing 15.7% of total employment in the EU27 in 2023, according to the EU-LFS). Additionally, within the manufacturing sector, robot use is concentrated in only a few subsectors, as documented earlier.



9 The standard deviation (SD) is as standardised measure of the amount of variation or dispersion of a set of values. A low SD indicates that the values tend to be close to the mean of the set, while a high standard deviation indicates that the values are spread out over a wider range.

> In the short term, close to the introduction of new automation technologies, the impact on employment takes the form of reassignment of workers directly involved in automated processes to other positions, tasks, and occupations. Nevertheless, it is important to underline that while no immediate labour displacement takes place, automation creates the conditions for job losses to materialise over the medium and long term, although this can be mitigated by increases in production.

For these reasons, to better understand the broader economic and employment impacts of automation today, it is crucial to complement this evidence with insights into its effects on other sectors that now encompass a larger share of the workforce. This is precisely the focus of section 3.3, where we examine the impact of automation on services. Before delving into that, however, we enrich the quantitative evidence on industrial robots' impact on employment with qualitative insights, concentrating on what happens in the automotive industry and the garment sector (3.2).

3.2 A qualitative analysis of automation in automotive and apparel

The automation of production processes at firm level requires technical feasibility as a precondition, but is influenced also by a range of other factors which include relative capital and labour costs, labour availability, skills requirements as well as the broader institutional setting where production takes place. In order to fully grasp these elements, a qualitative approach offers a useful avenue to better understand the decision-making process that leads to the automation of production processes, and also how this automation impacts on work and workers.

Against this background in 2021-2023 the JRC launched a project in collaboration with the International Labour Organisation to investigate the effects of automation on employment in the automotive, apparel and footwear industries in five countries, namely Germany, Indonesia, Mexico, Romania, and Spain. The main goal of the research, which was carried out through a set of case studies at establishment level, was to gain a better understanding of how processes of industrial automation and digitisation impact production processes, working conditions, jobs, task profiles within jobs, and the socio-demographic profiles of workers, with particular attention to gender. The automotive and apparel industries were selected because of their high degree of integration in global and regional supply chains, and also because of their very different situation in terms of automation and gender composition. On the one hand, the automotive sector is, as seen in the previous section, a highly automated one with a limited presence of women, while on the other the apparel industry is largely traditional and labour intensive, with a very high presence of women (Fana et. al., 2024).

Overall, the study painted a picture of incremental technological upgrading in both sectors, which in the most recent period is mostly shaped by the introduction of digital technologies that complement the previously existing machinery. While bottlenecks remain and full automation is a far-away prospect in both cases, significant advances in automation have taken place, mostly driven by an efficiency logic that seeks productivity gains and standardisation in production processes, very much along the lines of the main drivers behind platformisation of work and algorithmic management shown in chapter 5. Interestingly, in the case of the apparel industry a specific driver behind automation appears to be the limited availability of skilled workers as well as the increase in labour costs, together with other factors.

Table 2. Drivers and implications of automation according to case studies

Drivers automation	Efficiency logic and productivity gains
Impact Employment -	Reassignment of workers to other positions; no immediate net employment lossesr
Impact Productivity -	Productivity gains
Impact Working conditions -	Reduction in heavy and repetitive tasks; reduction of some workers' autonomy; tasks become more standardised and require less specialised skills; increased work intensity and a higher degree of worker monitoring through digital tools
Impact Psychosocial risks -	Improvement of health and safety for workers
Impact Gender impacts -	No defeminisation observed; more women in positions that become less physically intensive

Like in the previously summarised quantitative research, the case studies do not point towards a negative effect of the introduction of automation technologies on employment levels, while productivity gains do seem to materialise at firm level. In the short term, close to the introduction of new automation technologies, the impact on employment takes the form of reassignment of workers directly involved in automated processes to other positions, tasks, and occupations. Nevertheless, it is important to underline that while no immediate labour displacement takes place, automation creates the conditions for job losses to materialise over the medium and long term, although this can be mitigated by increases in production.

The impact of automation is however quite significant in terms of occupations and skills. Certain tasks become less labour-intensive, leading to a decline in the number or share of workers in those tasks. This is especially true for occupations characterised by heavy and repetitive tasks in both sectors. In the case of the automotive sector this has led to the recruitment of more women as line operators. In the apparel and footwear sector new jobs were created to monitor and programme machinery, as well as to operate specialized equipment and software. Overall, in the apparel and footwear sector we did not find evidence of defeminisation at the establishment level, while the automotive sector remains highly male-dominated (Fana et. al., 2024).

In terms of working conditions, the above-mentioned reduction in heavy and repetitive tasks had a positive effect and led to an improvement of health and safety for workers directly concerned by automation. At the same time, the case studies also revealed some evidence of a reduction of some workers' autonomy, as their tasks become increasingly standardised and requiring less specialised skills. In some cases, we also observed increased work intensity and a higher degree of worker monitoring through digital tools. These are psychosocial risk factors which are associated with a potential deterioration of mental health.

The automation technologies analysed in these case studies also show significant commonalities with the evidence shown in chapters 4 and 5. Indeed, we observe a strong push towards digitalisation driven by efficiency and productivity considerations. Combined with the automation component present in both industries, this depicts a picture of increased platformisation of work with algorithmic management features. It is thus not surprising that the findings in terms of streamlined work processes with stronger coordination and control mechanisms are similar in both cases. The different case studies show similar conditions for the deterioration of working conditions through increased worker monitoring and reduced autonomy.

3.3 What about automation in services?

An additional piece of qualitative research complementing previous findings and the algorithmic management case studies presented in chapter 5 points in a similar direction in terms of overall findings. This research was carried out in 2022 to complete the emerging picture of automation of work processes, focusing this time on the service sector. While, as shown in the previous sub-sections, there is ample evidence about automation in manufacturing, research on automation in services continues to be scarce, despite the fact this sector employs the majority of the workforce in all EU countries. The main reason for this is that, until recently, automation of work processes in the services sector was considered to be rather limited. A detailed review of the existing data on robots in services reveals that their penetration is currently extremely low in the European economy, especially when compared to industrial robots (Sostero, 2020). Moreover, service robots are used most often for manual repetitive tasks, in the parts of the service sector that are most similar to manufacturing, such as logistics, inspection and maintenance, and surface cleaning.

The limited presence of automation in services called for qualitative research, with an in-depth analysis of establishment-level case studies in the logistics, cleaning and health sectors in Italy (Cirillo et. al. 2022). In the logistics sector, which is highly digitalised, automated guided vehicles were studied. In the cleaning sector, the study looked at professional cleaning robots. Finally, in the health sector, the research focused on remote health monitoring devices which are deployed to support telemedicine platforms.

The main objective of this study was to analyse the main drivers behind the introduction of automation technologies in services, and the extent to which the selected technologies led to changes to the business model, tasks and occupations, work organisation, employment and working conditions at establishment level. The study also aimed at analysing how the technologies impact employee participation and industrial relations. As in other studies recently carried out, a key premise is that technological feasibility is far from being the only factor behind automation: organisational practices and routines regulating the work process as well as broader institutional arrangements play a key role in the introduction of these technologies and strongly mediate its effects on work coordination and working conditions.

Like the qualitative study on automation in manufacturing, these case studies showed that automation technologies do not displace labour in the service sector, but do reconfigure tasks and organizations (Cirillo et. al. 2022). The most visible changes in terms of reconfiguration of tasks and roles are observed in the logistics sector, in line with findings from our algorithmic management case studies and other research on this sector. In the cleaning sector, the case studies revealed a limited impact on tasks and responsibilities, while in the health sector we observed the creation of new roles in some of the cases. Overall, the analysis confirms the complexity in automating presumably low-value-added phases of service sector work: human labour remains crucial in conducting activities that require flexibility, adaptability and reconfiguration of physical tasks (Cirillo et. al. 2022).

Cost-effectiveness and efficiency considerations emerge as a key driver behind the introduction of these technologies, in line also with findings from other qualitative studies (see Table 2). Furthermore, in the logistic sector, business reconfiguration is an important factor shaping investment decisions. Obstacles to automation are diverse and range from technical unfeasibility, a high level of rigidity in the organisation, or even inadequacy of technologies available on the market. External and institutional constraints also play a role. These drivers and constrains are overall similar to the ones observed in other qualitative studies.

In terms of working conditions, results observed are diverse. Like in manufacturing, in cases where automation has reduced physical strain, there is a positive impact on ergonomics and occupational safety. This is particularly visible in logistics. Cleaning robots generate a paradoxical increase in the number of tasks performed by operators, who in addition to their previous tasks now also have to visually control the machine and maintain it, as well as clean and do the other scheduled work activities. In healthcare, there is an increase in workloads in some cases, while on the other hand some upskilling was also observed.

In terms of industrial relations, a general finding consistent with other case studies is an overall lack of involvement of workers and their representatives in decisions related to technology adoption and deployment. Unions rarely intervene in the matter of technological innovation, and this is understood and confirmed by the trade unionists themselves when declaring that they only ‘manage the outcomes’ of automation. The adoption was, in all aspects, a managerial decision: unions were never involved in the process, not even for safety- or training-related matters, and they were informed only when it was all set for the technology to be operational (Cirillo et. al. 2022).

3.4 Key findings and conclusions

To sum up, JRC research on automation has contributed in recent years to a better definition of key concepts, to a multidisciplinary investigation of the phenomenon and, especially, to the debunking of some narratives that are very present in research and public discussions in relation to the threats related to robots and automation technologies.

Our evidence has allowed us to confront simplistic narratives of jobs-stealing robots. Our research clearly shows that industrial robots have not had a major disruptive impact in the labour market and the economy so far. In fact, with the data available we cannot confirm that the use of industrial robots has negative implications for the labour market at all, not even when looking at their effect on low-skilled employment or their impact in terms of job polarisation. At the same time, we have shown that the increasing use of robots has contributed to the growth of labour productivity in the European industry. This implies that, contrary to the commonly mentioned fears about job losses and mass unemployment, industrial robots have had net benefits.

Qualitative studies show a mixed picture in terms of impacts of automation on work organisation and working conditions. In manufacturing there is no direct impact on job losses, but the conditions are there for these to materialise in the future. In some cases, working conditions improve, particularly in relation to reduced physical strain and improvements in safety at work. However, it is important to stress that the increased digital monitoring and the potential reduction of worker autonomy are important risks that deserve increased attention, as they are also observed in other case studies related to digitisation and algorithmic management (see chapters 5 and 5).

The impact of automation in services points in a similar direction: no labour displacement yet, combined with reconfiguration of tasks and roles, and diverse implications in terms of working conditions that can be a reason for concern in terms of psychosocial risk factors for workers' mental health. In the case of automation in services an important additional finding is the lack of worker (and unions) involvement in decisions regarding technology adoption. Additionally, qualitative studies point towards a higher prevalence of platformisation of work across traditional sectors, in line with the findings of chapter 5.

In general, our research on automation confirms two key insights: first, the most significant implications of the digital revolution for work and employment are not related to changes in net employment but to transformations in the nature of work itself and the coordination of work processes. Second, these impacts are strongly influenced by labor market institutions as evidenced by case studies in France, Italy, India and South Africa (see section 5.2).

What's next? With the recent advancements in generative AI, it is reasonable to speculate that some of these effects may be amplified in the future. AI has the potential to impact intellectual and social tasks that were previously less exposed to automation. At the same time, AI-powered automation and algorithmic management tools could become more powerful and efficient, increasing their capacity for control and monitoring of work processes and workers. In this context, we may anticipate a greater impact of these tools on work coordination and working conditions in the future.

THE DIGITISATION OF WORK

The concept of digitisation adopted in this report should not be confused with the very similar but broader concept of digitalisation. Whereas **digitalisation** refers to the general process of digital transformation of society and the economy, the narrower concept of **digitisation** refers to the (increasing) use of digital devices in work processes. More specifically, in the conceptual framework underlying this report, digitisation was defined as "the use of sensors and rendering devices to translate parts of the physical production process into digital information (strings of bits), and vice versa" (Fernández-Macías 2018). In other words, digitisation refers explicitly to the material basis of the digital revolution (the digital devices), and how they directly transform work processes in a technical and material sense. Essentially, what digitisation implies is capturing analogue information from the real world, translating it into a binary form so that it can be digitally stored, processed and communicated, and then retranslating it back into analogue form so that it can be fed back into the real world.

The added value of digitisation comes from the massive (and increasing) capacity and efficiency of computers for storing, processing and communicating information when it is in binary form. The digitisation of a process increases the amount of information available to control and optimise that process, while also allowing to store, process and communicate that information more efficiently. However, it is important to note that this necessarily implies some degree of standardisation and centralisation of information in the process that is digitised. The translation of analogue into binary information implies the quantification and standardisation of a reality which is originally qualitative and distinct. Digital tools that carry out the digitisation of work processes tend to be connected and centrally controlled by management. The information generated flows into centralised servers which store and operate with it for managerial purposes. In short, digitisation increases the efficiency of economic activity by centralising information flows and standardising information processes.

The earliest examples of digitisation of work processes concern the use of computers for clerical tasks, which started already in the 1980s. There are many examples of this: from invoices to time tracking, from payroll processing to document management or scheduling. Not so long ago all of these clerical tasks were conducted using paper, with manual processing by clerical workers; all of them are now largely carried out by (or with) computers. This has increased considerably the efficiency of clerical and administrative work, and the total amount of labour input necessary to carry out those tasks has declined as a result (Fernández-Macías et al. 2023).

In all of these cases, this involved a significant degree of standardisation of processes and centralisation of information. The conversion of information to binary and its processing with computers required using templates, predefined coding systems, additional metadata, naming conventions, numeric benchmarks, and so on. This implied not only a standardisation of information, but also of the associated work processes. And this standardisation itself implies a centralisation of control: the standards are generally set by management, and they facilitate the aggregation and centralisation of data. Since the mid-nineties, when office computers started being interconnected in networks, this centralising effect of digitisation has become even stronger. Centralised infrastructures and networks aggregate big amounts of data on all sorts of administrative and clerical processes, and this information can be analysed and utilised for managerial purposes.

A more recent (and advanced) example of digitisation of work is IoT (Internet of Things) systems (Grande et al. 2021). IoT systems are networks of interconnected devices, embedded with sensors and chips that enable them to collect and exchange all kinds of data on their environment. Compared to office computers, IoT systems are a big leap in the digitisation of work processes because they extend their reach to the physical world. IoT systems can be used for monitoring and controlling processes in agriculture or manufacturing, for managing warehouse inventories or logistic fleets, or any other physical economic activity. As with office computers used for clerical tasks, IoT systems rely on the collection and translation of data into binary form, which can then be centrally processed in real time. This allows for increased efficiency and optimisation but, as happened with office computers, also implies a big leap in standardisation and centralisation of information flows. IoT systems rely heavily on standardised data formats, and they tend to standardise the process that they monitor and control. And all of the information obtained from IoT systems flows into centralised servers and platforms, which operate and process this information for managerial purposes of optimisation and control.

In this chapter, we synthesise the main findings from our research over the last few years on the digitisation of work and its impact on work organisation and job quality. Although we did carry out some studies on the impact of digitisation on work in specific contexts (Grande et al. 2021; Urzi Brancati et al. 2021; Bisello et al. 2019), as well as some general studies summarising previous evidence in this respect (González-Vázquez et al. 2024; Urzi Brancati et al. 2022; see also Riso 2021), we conducted fewer studies targeted to this topic compared to the other “vectors of change” (automation and platformisation) of our work programme. However, given that digitisation is the material basis of all the changes related to the digital revolution (including those associated to the other two vectors of change), nearly all of our research over the last few years provided relevant insights with respect to digitisation as well. For these reasons, this chapter differs slightly from chapters 3 and 5, devoted to the other two vectors of change: it will be less focused on describing the findings from specific studies and more on transversal findings from this research programme over the last few years.

Our research did, however, focus on a particular modality of work which has been enabled by the digitisation of work: telework, which we can define as the remote provision of work via connected digital devices (Milasi et al. 2021; Sostero et al. 2021, 2023; Fana et al 2020). Telework requires the digitisation of labour input and of any interactions that take place within work (with colleagues or clients). The typical consequences of standardisation of processes and centralisation of information also apply in the case of telework. To support remote collaboration, telework demands an increased standardisation of workflows, often carried out within software management tools, and is often associated with standardised metrics for tracking labour input and performance (though not always). And the digital platforms used to coordinate labour input and collaboration in telework contexts are themselves systems for centralising information and control (Fana et al. 2022).

In this respect, telework poses a puzzle and an apparent contradiction, which is in practice resolved by the digital technologies used to coordinate it. How is it possible that a mode of work that implies a spatially decentralised provision of labour from each worker´s private space ends up leading to a standardisation of processes and a centralisation of control? The reason is that telework requires the use of networked digital tools, and these tools themselves embody the standardisation and centralisation functions that in an office or factory environment were traditionally carried out by human managers and supervisors. In this sense, telework provides an archetypical example of how digitisation transforms work processes, which is why we will discuss it in this chapter.

4.1 Digitisation, tasks and work organisation

Computers operate most easily on codified information, and thus they had their biggest (and earliest) impact on activities involving the operation with codified information such as text and numbers. Administrative processes, financial transactions and accounting, data analysis and statistics, were some of the activities which were earlier and most profoundly transformed by digital technologies. A significant amount of labour input for routine information processing tasks (such as calculating, text processing, data entry or record keeping) could be carried out by computers, displacing labour towards other tasks (such as customer relations or problem solving) or even towards other occupations (Bisello et al. 2019).

Subsequent advances in the encoding of unstructured data and rendering, together with the steep decline in the cost of chips and digital sensors, enabled two decades later (from the turn of the millennium) an increasing digitisation of physical production processes, as in the IoT systems previously discussed. This increasing digitisation of physical production processes could be combined with pre-existing automation technologies (such as robotics or autonomous vehicles) to facilitate the replacement of labour by machine input for some routine manual tasks which could not be automated with earlier mechanical systems (Fernández-Macías et al. 2021).

The current frontier in the digitisation of work is in tasks which do not lend themselves easily to standardisation, such as social interaction, creativity or problem solving. AI-enabled digitisation may be able to push that frontier as well (Tolan et al. 2021). Generative AI systems, when trained on very large databases of human interaction or human creations, can mimic human behaviour so accurately that in many cases they may be able to replace humans for those tasks in indistinguishable ways. The types of task content most affected (or transformed) by digitisation over the last few decades reflect the sequence of digitisation reaching different types of economic activity. Initially, computers mostly transformed routine information processing tasks; then, digital systems transformed both routine and non-routine physical tasks; and probably soon they will affect social interaction, problem-solving and other kinds of non-routine intellectual tasks.

How have these waves of digitisation impacted the organisation of work? In our research over the last few years, we have often found paradoxical and even in some cases seemingly contradictory effects of digitisation on work organisation (Fernández-Macías et al. 2023; Fana et al. 2020, 2022; Grande et al. 2021; Urzi Brancati et al. 2022). Digital technologies have routinised work and deroutinised occupational structures, increased responsibility while decreasing the autonomy of workers, expanded the channels and even the amount of communication while generating social isolation.

The routinising/ deroutinising effect of digitisation is perhaps the clearest and most important paradox we have found in our research in this respect (Fernández-Macías et al. 2023). On the one hand, as we are repeatedly arguing, computers can replace labour input for carrying out routine information-processing tasks. This effect can be observed not only within occupations (with a decline in the relative share of routine information-processing tasks for many professional and clerical occupations), but also in the overall distribution of employment across occupations. Mid-level clerical jobs have tended to decline in relative terms over the last few decades, compared to high-skilled professional jobs (and to a lesser extent also to low-skilled manual jobs).

This is the phenomenon known as routine-biased technical change, and which has been linked to an allegedly pervasive job polarisation trend across developed economies (for a discussion of this argument, see chapter 6). But what we found in our research is that simultaneously, the same computers that reduced labour input in routine administrative tasks for some occupations tended to increase the level of routinisation of other occupations, especially of professions which used to be characterised by being non-routine. (documents how routineness within occupations increased, even while employment in routine occupations declined).

This effect is also very clear: over the last two or three decades (coinciding with the diffusion of computers), professional occupations have seen a significant increase in the extent to which they are subject to standard procedures, numerical benchmarks and quality control systems, in most cases implemented through digital systems (Fernández-Macías et al. 2023; see also Bisello et al 2019). This implies a significant routinisation of professional occupations, which increasingly require filling in pre-defined forms, complying with institutionalized metrics, and adhering to codified workflows that leave less room for discretionary judgment or creativity.

Table 3. Aggregate reported and compositional change in task indices in EU-15, 1995–2015

	A. Aggregate reported change				B. Compositional change				C. Within-jobs change	
	1995	2015	Change	% change	1995	2015	Change	% change	Diff	% change
Repetitiveness	0,41	0,433	0,023	5.58***	0,463	0,447	-0,016	-3,42	0,039	9
Standardization	0,54	0,586	0,047	8.64***	0,591	0,581	-0,01	-1,69	0,057	10,33
Computers	0,27	0,444	0,174	64.24***	0,409	0,433	0,024	5,93	0,149	58,32

Footnotes:

*** P-value < 0.01.

Source: EWCS and EJM data.

Source: Fernández-Macías et al. 2023

A similar paradox can be observed with respect to the impact of digitisation on workers' autonomy. On the one hand, digitisation can result in an increase in responsibility and even discretion for workers, by shifting labour input from routine to cognitive tasks like data analysis and operational control, or social tasks like customer interaction. This was observed for instance in the case studies of IoT and 3D printing technologies in Spain, where workers reported more autonomy and responsibility after the introduction of these digital technologies (Grande et al. 2021). On the other hand, digitisation can also lead to increased monitoring and control, which results in decreased autonomy for workers. As previously explained, digital systems tend to standardise and codify work processes, making them more rigidly predefined and thus reducing the effective discretion of workers. The centralisation of information flows and control associated with digital tools often has a similar worker disempowering effect (Fana et al. 2022; Urzi Brancati et al. 2022).

How can we reconcile this apparent contradiction? The contradiction results from the dual nature of digital tools as complementary instruments of labour and as information control devices. As complementary instruments of labour, digital tools empower human labour, allowing it to be more effective and concentrate in what it does best: innovating, improvising and creating. Digital tools are wonderful multipliers of the cognitive abilities of human beings, and the more sophisticated they are the more powerful the multiplication effect. But on the other hand, work is not carried out in a socially neutral work setting, but within hierarchical structures under the command of managers. And digital devices are formidable data collection and analysis tools, which allow also a massive multiplication of the capacity of managers to monitor and control what happens in the workplace. Managers use digital devices to streamline work processes, increasing efficiency and control, and this directly reduces the autonomy of workers and increases the intensity of work.

Whether in a particular work setting digital tools lean more towards enhancing work rather than management will determine the ultimate effect on the autonomy for workers. Traditionally, increasing managerial control resulted in more efficiency but also more rigidity in productive structures, which put a natural limit on it (Piore and Sabel 1984). Digital tools, especially the latest generation of AI-powered ones, can increase managerial control while retaining a high level of flexibility, because the whole system can easily adapt to changing conditions or even changing objectives. This suggests that in the long run, the effect that will dominate is the enhancement of managerial control rather than the enhancement of work, and thus autonomy at work will tend to decline. In this sense, digitisation could be understood as a continuation of the secular process of rationalisation and bureaucratisation of work of which Weber spoke about more than a century ago (Baiocco et al. 2022).

"Digitisation could be understood as a continuation of the secular process of rationalisation and bureaucratisation of work of which Weber spoke about more than a century ago."

We briefly mention one final paradox concerning work organisation and digitisation: its impact on communication between workers. On the one hand, digitisation leads to a proliferation of communication channels and tools, which can make communication within organisations more fluid, faster and constant. With connected digital devices, workers can access more information, easily reach colleagues in different locations, and collaborate more effectively. On the other hand, the increased reliance on digital communication tends to reduce face-to-face interaction and lead to social isolation for workers. The clearest case of this effect is the situation of teleworkers, which we will discuss later; but even in office or shop floor situations, digitally-mediated communications tend to reduce face-to-face interactions (Fana et al. 2020; Grande et al. 2021; Urzi Brancati et al. 2022; Rani et al. 2024, González-Vázquez et al. 2024). This paradoxical effect is probably intrinsic to digital communication systems, and we can observe it not only in work settings but in society at large.

4.2 Digitisation and job quality

We base or discussion of the implications of digitisation for job quality on the framework of Muñoz de Bustillo et al. (2012), which distinguishes five broad dimensions of job quality, with a number of sub-dimensions. We will briefly discuss the four non-monetary dimensions of job quality, which are the ones we have studied in our recent research. The fifth one, concerning pay, is less directly affected by the digitisation of work and we have not researched it explicitly over the last few years. For a discussion of the impact of digitisation on employment and wage structures see chapter 6; for a discussion of digitisation and wages in the context of global value chains see Rodrik 2018. The four non-monetary dimensions are:

Intrinsic quality of work. This dimension has three components: skills, autonomy and social support. These are all aspects of job quality which are strongly connected to work organisation, and in the previous section we have discussed at length the implications of digitisation in this respect. In all three aspects, digitisation has paradoxical and contradictory effects, that ultimately depend on how and for what purposes it is implemented in each specific case. The routinising and deroutinising effects previously discussed have obvious correlates with skills, and we can argue that digital tools have had both upskilling and deskilling effects. On the one hand, digitisation often requires workers to develop technical expertise, digital literacy and data analysis capabilities (Grande et al. 2022). On the other, by standardising tasks and centralising decision-making, it can effectively deskill workers and turn them into algorithmically-controlled human automata (as happens in some logistics settings, see Cirillo et al. 2022 and Rani et al. 2024). As for autonomy and social support, we already discussed explicitly the same kind of paradoxical and contradictory results: digitisation can empower workers and foster collaboration but also reduce workers' autonomy and create social isolation.

Employment conditions. With respect to contractual stability, there is no clear evidence of any major impact of digitisation, although there can be an indirect negative impact to the extent that digitisation facilitates an increased fragmentation of production. There is ample evidence that digital tools have facilitated the increase in subcontracting and offshoring of the last three to four decades, which have resulted in increasingly fragmented value chains with uneven effects on employment conditions

(Sturgeon 2002; Baldwin 2016). Whereas in the lead firm employment conditions tend to be good, in the network of suppliers and subcontractors, they tend to be unstable and precarious (Weil 2014). In this sense, digitisation has probably contributed indirectly to the worsening of employment conditions in the long run. With respect to training and development opportunities (the second component of employment conditions in this job quality framework), the evidence tends to be more positive: the introduction of digital tools often requires new skills and firms often provide the necessary training, and this may be positive both in terms of lifelong learning and career advancement opportunities for some workers (Grande et al. 2021).

Health and safety. Digitisation tends to have positive implications in terms of physical risks at work, because it facilitates the automation of repetitive and strenuous tasks. Moreover, the increase in monitoring and information on work processes can have very positive effects for identifying potential hazards early. There are some potential negative effects in this respect, although they are probably less important: in particular, working with digital tools creates some particular physical hazards such as musculoskeletal strain from sedentary and unnatural postures, or eye strain. In terms of psychosocial risks at work, the evidence is less positive and in fact points towards exacerbated risk factors that can lead to stress, anxiety, due to some of the effects discussed in the conceptual framework in chapter 2 in terms of reduced autonomy, work intensification and social isolation (González-Vázquez et al. 2024).

Working time and work-life balance. Again, we find contradictory effects here. On the one hand, digitisation facilitates more flexibility in work organisation and work schedules, enabling flexible arrangements such as telework or hybrid work. These can in principle allow workers to balance their work and life more adequately, but the increased connectivity through digital tools combined with these flexible work arrangements can also lead to a blurring of boundaries between life and work which can be very negative for work-life balance and the general well-being of workers (Fana et al. 2020, González-Vázquez et al., 2024).

In short, with respect to job quality we observe the same dual and even contradictory effects of digitisation that we previously observed when discussing work organisation.

Box 2: Interactions between digitisation, automation and platformisation

The digitisation of work is linked to automation (discussed in chapter 3) in at least two important ways. First, it implies the collection of large amounts of data on work processes and on workers themselves. In principle, the employer uses this data primarily to optimise and increase the efficiency of work processes. However, with the increasing power of digital technologies – and particularly with the increasing ability of generative AI of mimicking human behaviour (provided it has sufficient training data) – the data collected on work processes can increasingly be used for automating them. This raises obvious fairness issues. Workers are paid for their labour input, not for the data generated by their activity: it seems reasonable to argue that workers should at least be entitled to some of the value generated by this data, especially if it can be used to put them out of work. Second, as we have repeatedly argued in this chapter, digitisation always entails a significant standardisation of work. And the standardisation of a process is an obvious precondition for its automation. This has been the case well before the digital revolution: even the earliest cases of mechanical automation using steam engines in the industrial revolution operated on highly standardised, unwavering and repetitive work processes. In short, both because it collects extensive data on work and because it standardises work processes, the current wave of digitisation is probably paving the way for future waves of automation.

The digitisation of work is also linked to platformisation (discussed in chapter 5) in important ways. Digitisation is a necessary precondition of platformisation, because digital platforms can only operate on work environments that have been digitised to a significant extent. But the link between digitisation and platformisation is stronger: something we have observed in our research is that the digitisation of work tends to lead to its platformisation (understood as the use of digital platforms for coordinating work processes). This is because digital platforms provide the most efficient form of coordinating digital transactions of any kind, and the more digitised a work process is, the more the interactions of workers between themselves and with managers (and clients) tend to go through digital means. In fact, most of the centralised systems of control of digitised work processes can be considered to be digital platforms in one way or another. In other words, digitisation also tends to foster the platformisation of work.

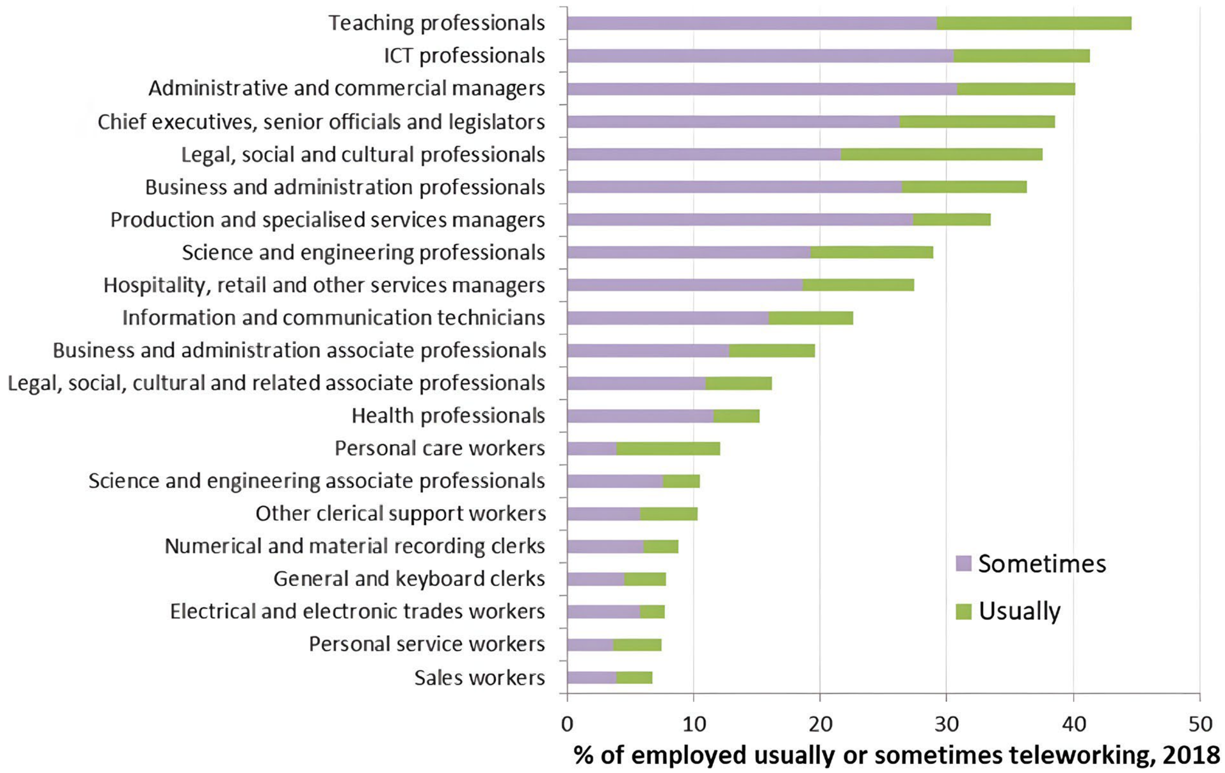
4.3 Telework, a modality of work enabled by digitisation

Although working from home is certainly not a new phenomenon, the remote provision of labour input into complex productive processes is not feasible at a large scale without the information and communication technologies which became widely available with the digital revolution, especially after the diffusion of the internet at the turn of the millennium. The widespread availability of connected digital devices allows a very efficient remote provision of labour input for information-processing tasks, and increasingly also (with the widespread availability of high-speed internet, allowing high quality videoconferencing) for social interaction tasks which do not require physical contact. In other words, telework can be considered a modality of work enabled by digitisation.

However, even though the devices, infrastructure and competences for the remote provision of labour have been there for decades, telework did not really take off until the COVID crisis as a common work modality (Milasi et al. 2021). It is unclear why this was the case, but based on our own research on the large-scale shift in telework practices during the pandemic we have advanced some hypotheses in this respect (Sostero et al. 2020, 2023). In our view, the use of telework before COVID was hindered by cultural norms and practices around work, in particular relating to hierarchy and control. The widespread preference for direct managerial control of workers, which is obviously difficult in a telework context, limited its use before COVID despite its obvious technological feasibility in already highly-digitised and connected work environments.

Only for managers and professionals was telework relatively more common (but still not much) before COVID (see Figure 6). First, because occasional teleworking was an additional privilege of the upper echelons of organisational structures, a conspicuous demonstration of organisational trust and managerial commitment. Furthermore, the work of managers and professionals is in any case intrinsically more difficult to control directly, and thus the risks of unsupervised remote work were considered less problematic from a managerial perspective. Mid- and low-level clerical and information-processing workers, whose task contents allow for easy telework with basic ICT equipment, but whose hierarchical position put them under direct managerial and supervisory control, very rarely teleworked before COVID (Milasi et al. 2021).

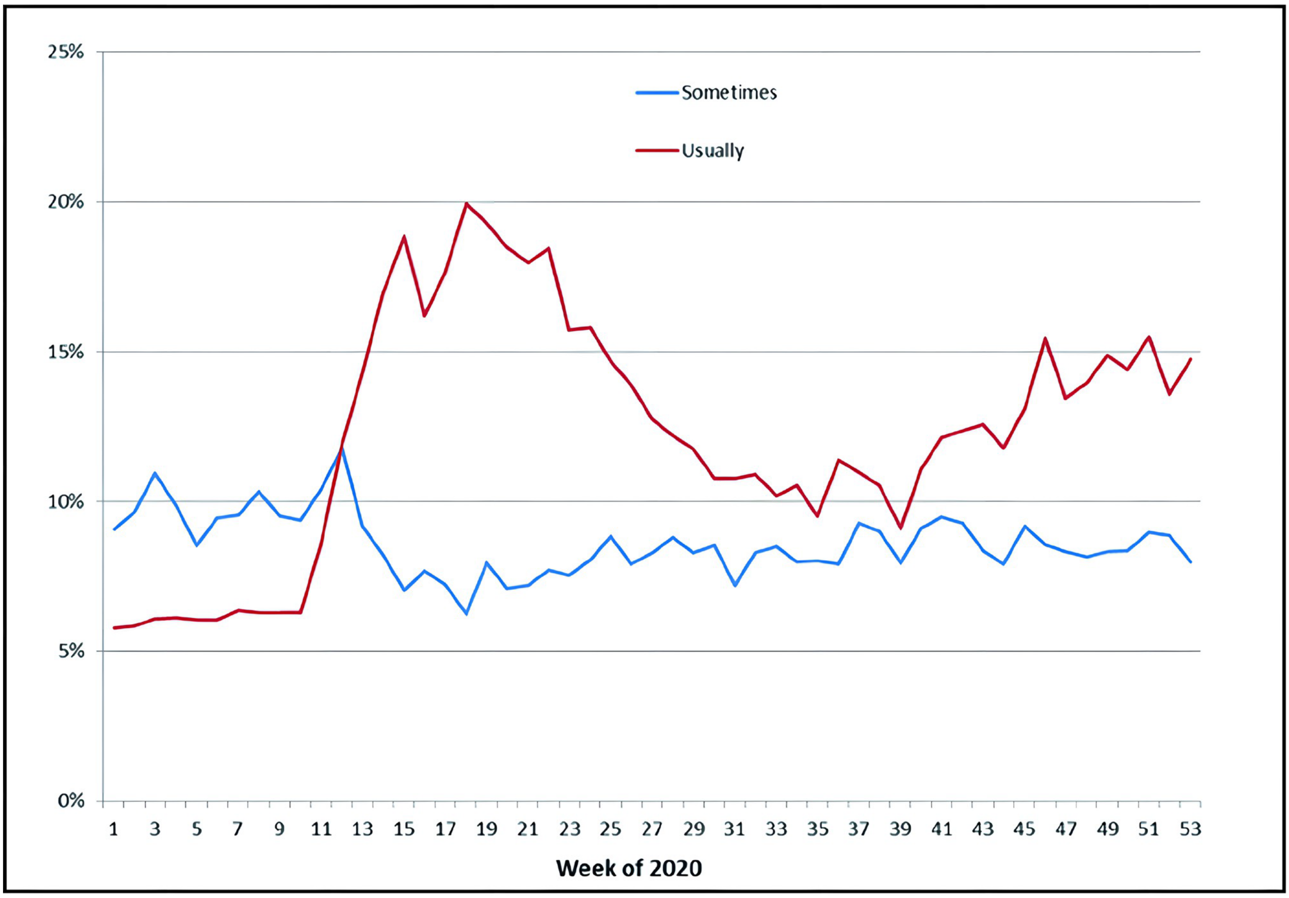
Figure 6. Prevalence of telework by occupation, EU27



Source: JRC calculations from ad-hoc extractions of EU-LFS data provided by Eurostat.

Source: Milasi et al. 2021

Figure 7. Weekly share of employee usually (sometimes) working from home, EU27 (2020)



Note: Employees only. Figures refer to the weighted data for EU27 countries combined.
Source: Authors' calculations from EU-LFS ad-hoc extractions provided by Eurostat.

Source: Sostero et al. 2023

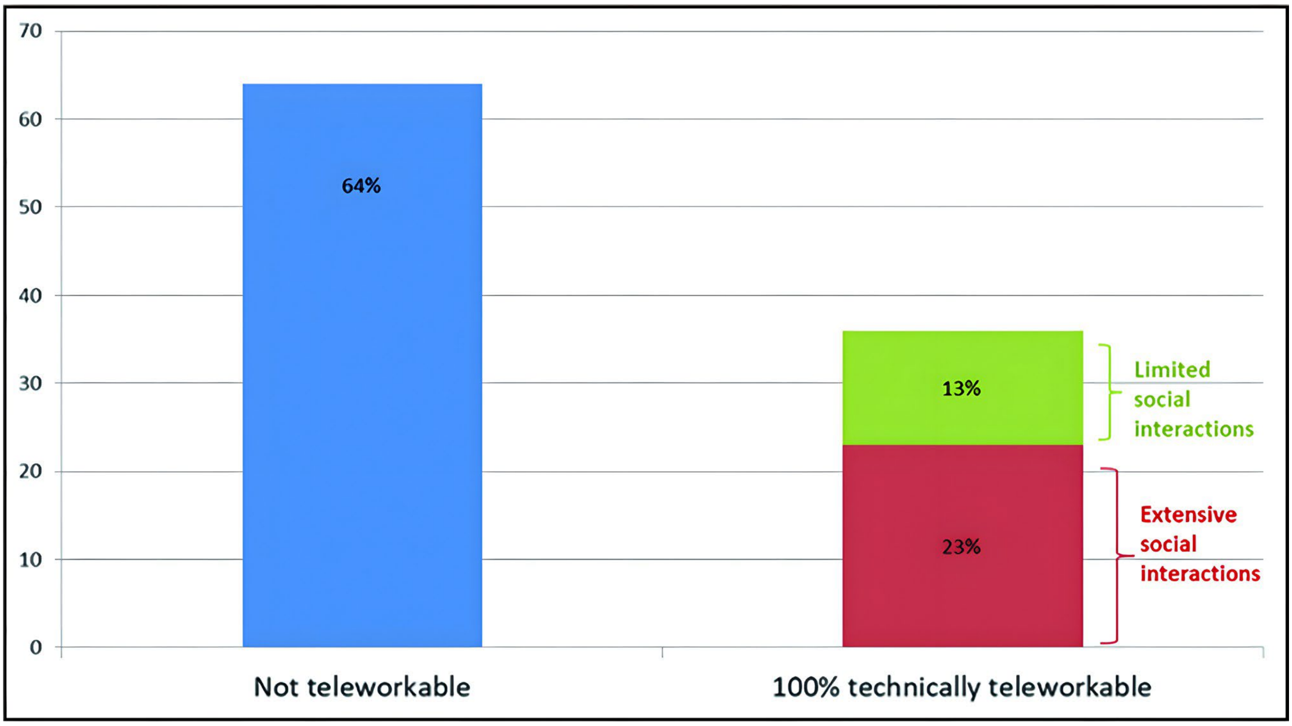
This was abruptly changed by the pandemic in 2020, a brutal exogenous shock that forced governments, companies and private citizens to reduce social interaction to the minimum (for an initial assessment of the employment impact of the COVID-19 crisis in several EU countries, see Fana et al. 2020), and everyone who could work from home had to do so at once. All of a sudden, there was a massive adoption of telework, and technical feasibility was the sole determinant of who teleworked or not. This forced organisations to adapt very quickly, developing new practices and adopting new managerial tools for the coordination of remote workforces. These tools were mostly digital platforms that incorporated functions of worker communication and collaboration, but also of digital monitoring and algorithmic management. With the success of these systems and of the COVID large-scale telework experiment, many companies and managers embraced telework as a legitimate alternative to centralised office work while also consolidating and

> Telework increased massively as a result of the covid-19 pandemic, which forced governments, companies and private citizens to reduce social interaction to the minimum, and everyone who could work from home had to do so at once.

expanding platformisation of work practices, as explained in chapters 2 and 5. Although currently telework is not as high as it was during the COVID pandemic, it is much higher than before (see Figure 7 and Sostero et al. 2023).

Telework implies a change in how we work rather than what we work on, and thus it affects less task content than work organisation. In fact, task content is a determinant of the possibility to telework, rather than telework being a determinant of task content. In our research, we developed the concept (and associated measures) of **teleworkability**, defined as the technical feasibility of working remotely with existing digital technologies (Sostero et al. 2020, 2023). The key bottleneck for teleworkability in our approach is the need to physically interact with things or people: given the state of current digital technology, this type of labour input cannot be remotely provided (there are experiments with remotely controlled robots that may change this in the future, but as of today this is not practically relevant). On the contrary, labour input which involves processing information, or interacting with people but not physically, can be carried out remotely with existing digital tools. However, the fact that a particular type of labour input can be technically provided remotely does not mean that it will necessarily be provided with the same quality. As a secondary determinant of teleworkability, we argued that the quality of the labour input provided varied depending on the extent to which it required complex social interaction. Given that existing videoconferencing and remote communication tools are inferior to face-to-face communications for complex social interaction (because some of the nuances of non-verbal communication are necessarily lost), telework has a penalty in terms of quality of the labour provided for complex social interaction tasks (Sostero et al. 2020, 2023). In Europe, around 36% of employment is technically teleworkable according to our approach, and roughly one third of this is in occupations with limited social interaction and thus teleworkable without a significant drop in quality (see figure 8).

Figure 8. % of EU dependent employment by level of teleworkability and social interaction



Source: Sostero et al. 2023

> In Europe, around 36% of employment is technically teleworkable according to our approach, and roughly one third of this is in occupations with limited social interaction and thus teleworkable without a significant drop in quality.

In terms of work organisation, the impact of telework is significant. As we have repeatedly argued, telework in itself makes the direct supervision and control of work very difficult (or indeed impossible). A qualitative study we carried out during the pandemic surge of telework provided useful evidence of this (Fana et al. 2020; see also Fana et al. 2022). In the initial period after the unexpected shift to telework, many of the workers interviewed (especially those in mid-level occupational categories) reported an increase in their work autonomy and even the emergence of some spontaneous forms of self-organisation. It is important to note that this initial autonomy and self-organisation was not simply the result of pandemic chaos and the interruption of normal work. The interviewees emphasized that this self-organisation was explicitly oriented to maintaining workflows and previous tasks and objectives, to the extent that it was possible (although it probably also provided workers with a sense of belonging and normality which was very necessary in those difficult and uncertain times). In any case, as remote working arrangements stabilised, managers implemented new tools for remote collaboration that allowed them to regain control, mostly using digital platforms for coordinating remote work, as previously explained.

In this sense, telework implied a shift from direct to bureaucratic-digital forms of control in work processes (Fana et al. 2022). The big shift to telework during COVID accelerated pre-existing trends of digitisation, with the associated effects of standardisation of processes and centralisation of information flows and control that we have extensively discussed in this chapter. Also, it extended the use of digital platforms for the management of labour to many sectors and activities where they were seldom used before (Fernández-Macías et al. 2023). When the pandemic was over, even where telework was reverted to face-to-face office work (or some kind of hybrid partial telework arrangement), these changes in terms of digitisation and platformisation remained.

With respect to the impact of telework on job quality, our results are again ambivalent (Fana et al. 2020; Sostero et al. 2020). While some workers appreciated the increased flexibility and autonomy gained from working from home, some others resented the lack of direct social interaction and the blurring of the boundary between work and private life. As telework is generally carried out in front of screens, the usual risks of musculoskeletal and sight disorders of digitised office environments also apply, and the lack of face-to-face social interaction with co-workers (or clients) can lead to feelings of social and significant psychosocial risks (González-Vázquez et al. 2024). However, given that telework takes place in the private homes of workers, its effect on the well-being of workers is particularly affected by gender and household composition. For instance, female workers with small children, who tend to face much higher workload in terms of family responsibilities because of the persistence of traditional gender roles, can hand benefit more from the flexibility afforded by telework, but also suffer much more from the blurring of boundaries and the accumulation of burdens at home (Fana et al. 2020). In this way, telework, as a form of digitisation and a newly consolidated mode of work, might ultimately be used to reproduce and reinforce traditional gender roles. This could help explain why female teleworkers report more negative impacts on their mental health and job satisfaction compared to their male counterparts (Castro-Trancón et al., 2024).

4.4 Key findings and conclusions

This chapter has discussed the work and employment implications of digitisation, focusing on its material basis – the use of digital devices to translate physical processes into digital information. Building on our research on this topic over the last few years, we have argued that digitisation, while increasing efficiency through enhanced information processing and communication, also introduces standardisation and centralisation of information flows. From early applications in clerical tasks to the more recent advancements in IoT systems, digitisation has steadily extended its reach across various economic activities, with profound and often contradictory consequences for work organisation and job quality.

Our research has highlighted a series of paradoxes inherent in the digitisation process. We have found that while digital technologies can displace labour input in routine tasks, they simultaneously increase the routinisation of professional occupations. This is because these technologies standardise workflows, imposing predefined forms and metrics, thereby limiting discretionary judgment and creativity. Similarly, digitisation has been shown to both empower and disempower workers, by increasing responsibility while decreasing autonomy, or expanding communication channels while generating social isolation. This is partly because digital devices have a dual nature as complementary instruments of labour, which can multiply the cognitive capacities of workers, and as information control devices that can enhance managerial oversight. Whether a work setting is more oriented to enhancement of work or managerial control determines the ultimate impact on workers.

These dual effects extend to our discussion of job quality. Digitisation can upskill workers by requiring new technical expertise, but also deskill them through task standardisation. The flexibility offered by digital technologies may improve work-life balance, but the blurring of boundaries between work and life can create stress and negatively influence well-being, particularly for women and those with caregiving responsibilities. In terms of health and safety, the physical risks of working are reduced in general, although we observed some specific forms of physical and psychosocial risks linked to working with digital devices.

The case of telework is paradigmatic in this respect. Telework highlights the tension between decentralised work locations and the standardisation and centralisation effects of digitisation. What initially appears as a decentralised mode of work in fact depends heavily on digital tools that embody the functions of standardisation and managerial control.

Although the extent of digitisation of European workplaces is already very high – more than two thirds of European workers regularly use digital tools for work, according to AMPWork data (Fernández-Macías et al. 2023) – it will continue developing both in extent and depth in the foreseeable future, and the JRC will continue researching it. But there are two specific trends that, as of today (early 2025), seem particularly important and will require additional research in this respect.

On the one hand, the recent impressive advances in AI suggest that very soon many, if not all, digital devices will incorporate AI capabilities that will make them smart in a literal way. Rather than passive tools operated by human workers, digital devices can thus become active agents with the capacity to react and operate on their environment according to some pre-established parameters and goals. This has obvious implications for the workers who will interact with them, exacerbating some of the benefits and risks that we have discussed in this section, but creating others that are yet difficult to foresee. There is an urgent need to study and understand better the potential implications of the addition of AI capabilities to digital tools at work.

On the other hand, human civilisation is facing an existential challenge because of the environmental impact of its recent reliance on fossil fuels as main source of energy. To confront this challenge, economic processes will have to be profoundly transformed until they become more environmentally sustainable, shifting away from fossil fuels and drastically reducing waste. Digital technologies will probably play a key role in this transformation, because they can help improve process efficiency and also because they can dematerialise goods and services at a large scale. At the same time, digital technologies generate massive amounts of waste and consume huge amounts of energy (Muñoz de Bustillo 2024). Thus, the quest for environmental sustainability is likely to give a further push to the digitisation of economic activity, but digitisation can have in turn a negative environmental impact. The synergies and contradictions between the digital and green transitions, and their implications for work and employment, are also topics which require a better understanding and which we will continue to study in the future.

> “Telework highlights the tension between decentralised work location and the standardisation and centralisation effects of digitisation. What initially appears as a decentralised mode of work in fact depends heavily on digital tools that embody the functions of standardisation and managerial control.”

THE PLATFORMISATION OF WORK

Economic activities and workplaces are becoming increasingly digitised and interconnected. This expands the use of platforms and algorithms in all kinds of organisations, since they are the most efficient mechanisms for coordinating digital interactions of any kind (Fernández Macías 2017).

In previous chapters, we have analysed how automation and digitisation change the nature of work in the EU, with often important implications in terms of work organisation and working conditions. Digital technologies have indeed been a key driver of the emergence of new forms of work in the EU in the last decades, such as work mediated through digital labour platforms. They make working remotely easier than ever, allowing firms to adopt a more agile and flexible organisational structure, and enabling new forms of work organisation (González Vázquez et. al. 2019).

Digital labour platforms are no longer new or unknown in the EU. They have become part of our daily lives and are now consolidated as a small but significant reality in EU labour markets. They entail technological infrastructures in which algorithms are used to match clients who need a service with workers who are able to provide that service, and to coordinate the provision of those services. In general, digital labour platforms used for coordinating work processes tend to incorporate functions of digital monitoring and algorithmic management (Fernández-Macías 2017). These functions create hierarchical power structures that make platforms similar to traditional employers, with the providers of labour services being in a de facto subordinate position vis-a- vis the algorithms (Urzì Brancati et al. 2020).

Originally platform work was perceived as a quickly rising new and atypical form of employment, but in recent years it has consolidated but also stabilised as a marginal phenomenon in the EU. What we think is more important and significant is, as we saw in chapter 2, the


SMART MACHINE
AI
ALERT
1203
538 1203

fact that some of the key features of platform work, and in particular its digital monitoring algorithmic management features, are quickly extending to regular workplaces. Indeed in recent years, and particularly since the pandemic, we see an increasing presence of these technologies and new ways to organise work in conventional work settings. This use of platforms and algorithms for the coordination of work processes is especially visible in large firms and in sectors such as logistics, and to a lesser – but expanding – extent also retail, manufacturing, marketing, consultancy, banking, hotels and call centres (Wood, 2021).

In fact, the generalised digitisation of all economic activities creates a material base for this phenomenon throughout the economy, and this implies a certain convergence in the use of platforms and algorithms for the coordination of work both in conventional organisations and digital labour platforms. This phenomenon, to which we refer as the platformisation of work, expands standardisation, bureaucratisation and digitally-enabled control to all kinds of activities, entailing very relevant changes in work organisation with often negative implications in terms of working conditions. Our evidence shows that these 'platformised' regular work environments are based on streamlined, more efficient work organisation which in certain circumstances – strong institutional frameworks and worker participation mechanisms – do not translate into negative implications for workers, but these technologies intrinsically exacerbate risks in terms of intrusive monitoring, intensified work environments, less autonomous work, etc.

This chapter delves into these new forms of work (digital labour platforms) and, more importantly, these novel forms of work organisation based on 'platformisation', as well as their socio-economic impacts and regulatory challenges.

5.1 Platform work: a consolidating but marginal form of employment

Over the past decade, the widespread use of digital devices, the generalisation of high-speed broadband connectivity for large shares of the population and the development of digital technologies (such as artificial intelligence and cloud computing) have enabled digital economic transactions and the remote exchange of services, data and information between individuals, businesses and devices (ILO, 2021). This phenomenon, usually referred to as 'digital economy', was originally often labelled as 'collaborative economy' highlighting its potential benefits. It is now evident, however, that it has many – and often negative - societal and socio-economic implications that were initially poorly understood. This has given rise to increasing attention by researchers and policy practitioners across the EU and the world. The digital economy builds on the use of digital platforms, understood as digital networks that coordinate transactions (and in particular economic activities) in an algorithmic way (Fernández-Macías 2017).

The surge of work mediated through digital labour platforms

Digital labour platforms can be described as digital networks that use technology, such as software algorithms and data analytics, to connect workers with clients, manage work assignments and transactions, and monitor worker performance. Digital platforms can be online web-based tools through which tasks or work assignments, usually highly qualified professional services, are performed online or remotely by workers, or location-based platforms, where tasks are performed in person in specified physical locations, including transportation, delivery or home services (ILO, 2021).

Platform workers use a variety of digital tools, such as computers or laptops, mobile phones and tablets, to carry out their work. In turn, these tools are generally able to collect data on workers, and this data is one of the crucial components of the proper functioning of these algorithms. Data need to be collected from different sources, which implies that almost every worker can be subject to monitoring and tracking. Such data are then processed and fed to algorithms that carry out automated actions, such as assigning shifts and tasks, providing instructions, evaluating performance and disciplining behaviour. This is generally referred to as 'algorithmic management' (Pesole et. al. 2018). Digital labour platforms have been at the vanguard of digital monitoring and algorithmic management practices (Pesole et al. 2018, ILO 2021), due to both the setting they operate in, being entirely in the digital space, and also due – until recently – to the lack of a proper regulatory framework in the EU.

JRC research on digital labour platforms started in 2017 under the Collaborative Economy (COLLEEM) project. Its initial aims were to provide an up-to-date overview of digital labour platforms and to collect data on what – back then – was an emerging reality. This included socio-economic profiles of platform workers, their motivations for using labour platforms, the type of services they provide, the remuneration they obtain, and the frequency of the services. From the beginning, we paid significant attention to the potential new opportunities that could be derived from platform work, but also to the challenges related to this new form of work. The potentially disruptive implications of digital labour platforms for traditional labour markets were already being discussed but there was very limited robust evidence about them. At the time, there were already visible signs of an increasing fragmentation of work in the EU, not only in the growing number of platform workers, but also in the declining job tenure and fewer working hours.[10] The challenges that these then-called 'non-standard' or 'atypical' forms of work posed – in terms of increased precariousness of workers, unclear employment status and potential discrimination – were not well understood and required in-depth analysis (González Vázquez et. al. 2019).

Given the lack of data about platform work in Europe, the first steps in our research agenda were to carry out in 2017 and 2018, the **JRC-COLLEEM surveys**[11]. These surveys provided a first comprehensive assessment of work mediated through digital labour platforms in Europe. One of the main contributions of the COLLEEM surveys was a comparable measurement of the prevalence of platform work, taking as a basis the frequency and regularity of the work via platforms, as well as the income generated by it. In addition, these surveys provided valuable insights into the socio-economic profiles and working conditions of platform workers. This shed light on a previously under-examined segment of the labour market and allowed a better understanding of the challenges facing platform workers, as well as their policy and regulatory implications. In this section we summarise the main findings from the COLLEEM surveys, how they changed our understanding of platform work in the EU and what the situation looks like at the moment, seven years after the first survey.

The prevalence and socio-economic profile of platform workers in Europe

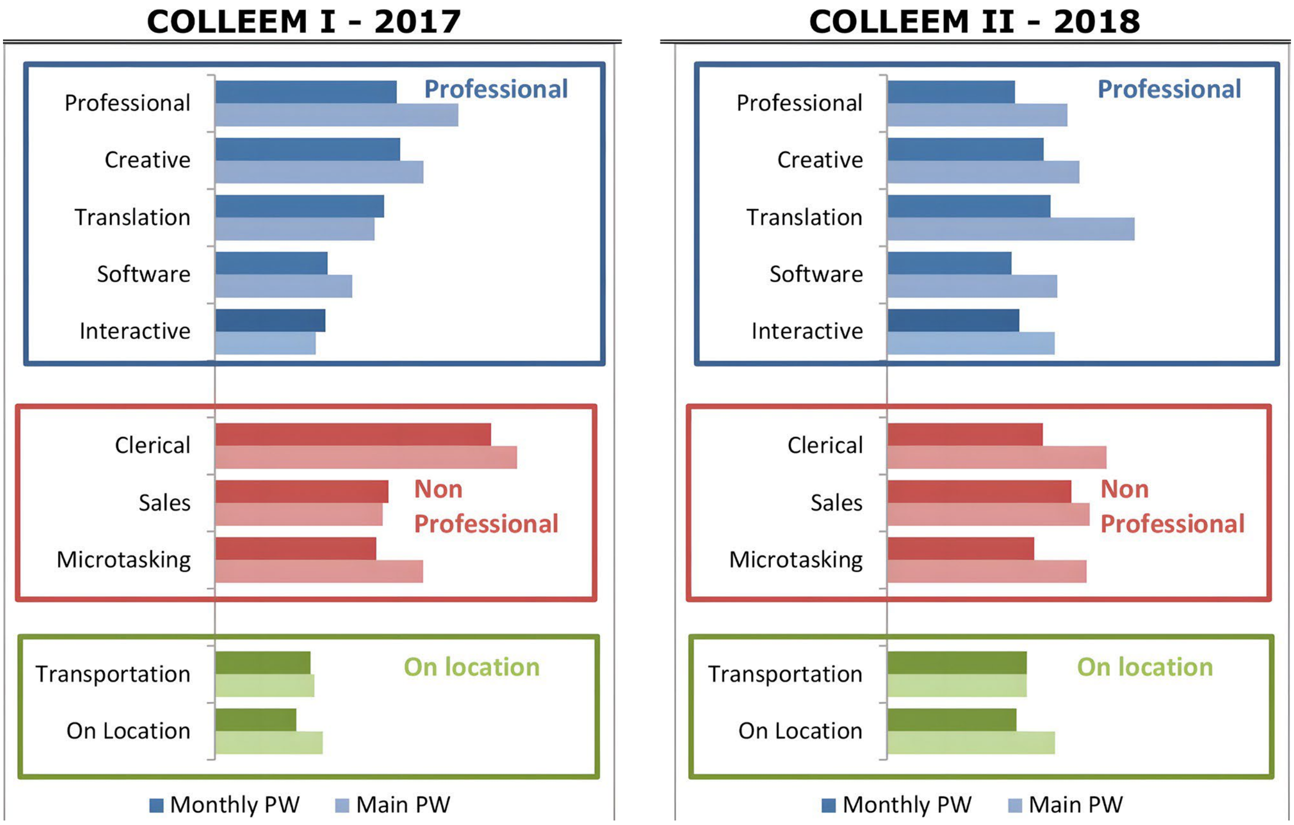
Estimates from COLLEEM II showed that, in 2018, on average 1.4% of the respondents in the surveyed countries provided services via digital labour platforms as their main job. These are the workers that we classified as "main platform workers", meaning workers who claim to work more than 20 hours a week providing services via digital labour platforms or earn at least 50% of their income doing so. The raw prevalence of platform work is obviously higher if we relax the definition in terms of frequency, hours and income generated from platform work. For example, 4.1% of the working-age population provided labour services via platforms as a secondary job. These figures include platform workers providing services both digitally (e.g. freelancing, clerical and data entry) and on location (e.g. transport, delivery, housekeeping, etc.). The 2018 data showed that platform work was a small but significant new form of work, and that it was consolidating in EU labour markets (Urzi Brancati et. al., 2020). The more recent AMPWork survey (see also section 5.2), conducted face-to-face in Spain and Germany in 2022, confirmed this reality: a small and relevant form of work (2.1% of the working age population in Spain and 0.8 in Germany), but no longer new and increasingly well understood (Fernández Macías et. al., 2023). The 2022 AMPWork data also confirmed the main features of our characterisation of platform workers. Generally, the typical platform worker tends to be younger, more educated, and more likely to live in a larger household with dependent children. The average age of platform workers is just below 34 years, while close to 60% of those who provide services on platforms as their main job have at least tertiary education. Platform workers are also more likely to be male and foreign born, especially if performing on-location tasks.

Our analysis showed that the majority of platform workers in Europe provide highly skilled online services, but the share of on-location service providers has been expanding. On average, half of the platform workers perform both online and on-location services and are active on two or more platforms. According to our data most platform workers provide professional services (such as software development, writing or translation) which demand high skill levels. In particular, a large and growing proportion of main platform workers provided translation services, a trend partly reflecting the growing engagement of women in platform work (see Figure 9).

10 For a detailed analysis of trends in working time in Europe over the past decades, see Torrejón Pérez et al. (2024).

11 These surveys relied on data collected through online panel surveys in several EU Member States. The first COLLEEM pilot survey gathered 32,389 responses from 14 Member States. The second pilot (the COLLEEM 2018 survey) gathered 38,022 responses from internet users aged between 16 and 74 years old in 16 EU Member States: Croatia, Czech Republic, Finland, France, Germany, Hungary, Ireland, Italy, Lithuania, the Netherlands, Portugal, Spain, Sweden, Slovakia, Romania, and the United Kingdom.

Figure 9. Types of work via digital labour platforms



Source: Urzi Brancati et al. 2020

The unclear employment status of platform workers

Early JRC research on digital labour platforms confirmed the initial intuition that the unclear employment status of platform workers was a major challenge, highlighting a significant regulatory loophole. COLLEEM II data showed that, in most cases, remuneration for platform work is based on the tasks performed (61% of the total). However, importantly, a significant proportion of platform workers – up to 51% of those for whom platform work is their main activity – also receive fixed daily, weekly or monthly remuneration, which is typically associated with dependent employment. This reinforced the idea that, in many cases, platform workers have a status that is closer to that of employees than to independent contractors.

This was also supported by data on how the workers perceive themselves: when asked about their current employment situation more than 70% of frequent[12] platform workers surveyed in COLLEEM II claimed to be an employee, and another 10% self-employed. COLLEEM II data also suggested that many platform workers have a regular job as a main activity and engage in platform work as a secondary source of income (Urzi Brancati et. al., 2020). Overall, the difficulties in classifying platform workers according to standard regulatory frameworks has been a major challenge until recently. The recent entry into force of the new EU Directive on the working conditions of platform workers is a major step forward in creating a clear and homogeneous framework across the EU. At global level, ILO research has confirmed that working conditions on digital labour platforms are largely regulated by terms of service agreements, that platform workers are often unable to engage in collective bargaining and that most workers on digital labour platforms do not have social security coverage (ILO, 2021).

The diversity of working conditions in digital labour platforms

Working conditions vary considerably across types of platform workers. Respondents who predominantly provide professional services are typically better paid than other

12 We defined “frequent” platform workers as those who provide services at least once a month in the previous 12 months.

types of platform workers, but also more likely to face stressful situations. On the other hand, non-professional online platform workers, while facing less stressful situations, are more likely to perform routine tasks (e.g. data entry, micro-tasks) and to have few learning opportunities. Importantly, workers' conditions tend to worsen with the intensity of platform work. For instance, more than half of main platform workers consider their work via online platforms to be stressful. In terms of working hours, three quarters of the platform workers surveyed work less than 30 hours a week, although 13% of platform workers report very long working hours, in excess of 60 hours a week. Ultimately, findings suggest that the working conditions of platform workers are very heterogeneous, depending on the type of work performed, its intensity and frequency (Urzi Brancati et. al. 2020).

Platform work today: small but significant and increasingly regulated

Platform work is a clear example of how the digital transformation can offer new job opportunities while creating policy challenges. Since we started working on this subject in 2017, our understanding of platform work has come a long way. Platform work is neither a disruptive model of collaboration, as it was often seen originally, nor a quickly rising atypical form of work. In fact, there is now growing consensus that platform work has become a consolidated form of employment, still a non-standard one but also quite marginal, involving many young people and highly educated workers, but also many on-location service providers. However, platform workers tend to face particular risks with respect to job quality, privacy and control which require particular attention.

> “Platform work is neither a disruptive model of collaboration, as it was often seen originally, nor a quickly rising atypical form of work. In fact, there is now growing consensus that platform work has become a consolidated, if marginal, form of employment.”

Furthermore, it is still the case that platform workers risk having an unclear employment status. This has led to many policy initiatives and court cases across Europe aimed at clarifying the nature of the relationship between digital labour platforms and their workers, but also a fair amount of regulatory action, at both national and European level. In the EU, the new Directive has been a key milestone, but further policy action is likely to be needed in the future to address the expansion of key features of platform work into traditional workplaces.

5.2 The rise of new forms of digital monitoring and algorithmic management

Data collection, worker monitoring and algorithmic management

A growing body of literature describes the expansion of algorithms as mechanisms of work coordination and monitoring from digital labour platforms, where they originally emerged, into traditional work settings. However, the real magnitude of this phenomenon and its consequences are still not sufficiently understood. '**Algorithmic management**' most commonly refers to the use of technologies to manage – direct, evaluate and discipline - and coordinate the workforce, going hand in hand with data collection and worker surveillance (Lee 2015, Mateescu and Nguyen 2019, Kellogg et. al. 2020, Wood 2021, Parent Rocheleau et. al. 2021).

The JRC has been paying increasing attention to this new reality since 2020, from original conceptual work towards to what has now become an ambitious and fully-fledged research agenda on this topic. In line with Lee et. al. (2015) and Kellogg et. al. (2020), algorithmic management involves supplanting management functions with machines that exercise at least some level of decision-making authority over workers, including the full or partial automation of direction, evaluation and discipline or rewards (Doellgast et. al., 2023). It is indeed useful to look at algorithmic management through the lens of the six mechanisms of algorithmic control defined by Kellogg at al. (2020), according to whom algorithms may be used “to direct workers by restricting and recommending, evaluate workers by recording and rating, and discipline workers by replacing and rewarding” (Kellogg et al. 2020, p.36). Such mechanisms are fundamentally different from other earlier forms of control and their outcomes are primarily disempowerment and stress. Drawing on these six mechanisms Wood (2021) proposes a classification of algorithmic management based on the embedded level of automation of the main managerial functions: direction, evaluation and discipline.

Our original approximation to algorithmic management defined it as “the use of computer-programmed procedures for the coordination of labour input in an organisation” (Baiocco et. al., 2022). As shown in Figure 10, by supporting or automating management functions, algorithmic management can have a wide range of implications for the organisations that adopt it and for the workers involved. A key feature of algorithmic management is that it tends to standardise work processes, facilitating the contracting of labour input from outside the organisation. As algorithmic management spreads to the wider economy, it will likely extend at least some of these business practices to other sectors, segmenting value chains and transforming employment relationships. These changes in work organisation can have implications on working conditions and, therefore, on job quality. Algorithmic management enables business models that rely on organisational models that assign tasks and jobs beyond the boundaries of the organisation. It can thus contribute to fissured and precarious employment relations and, ultimately, undermine labour standards.

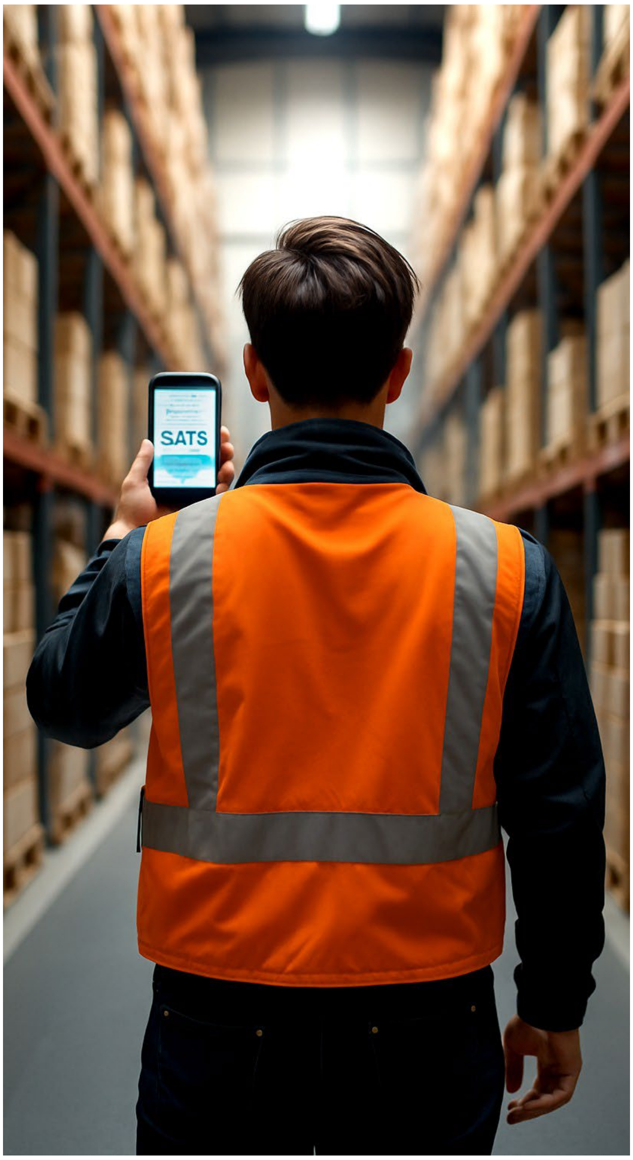
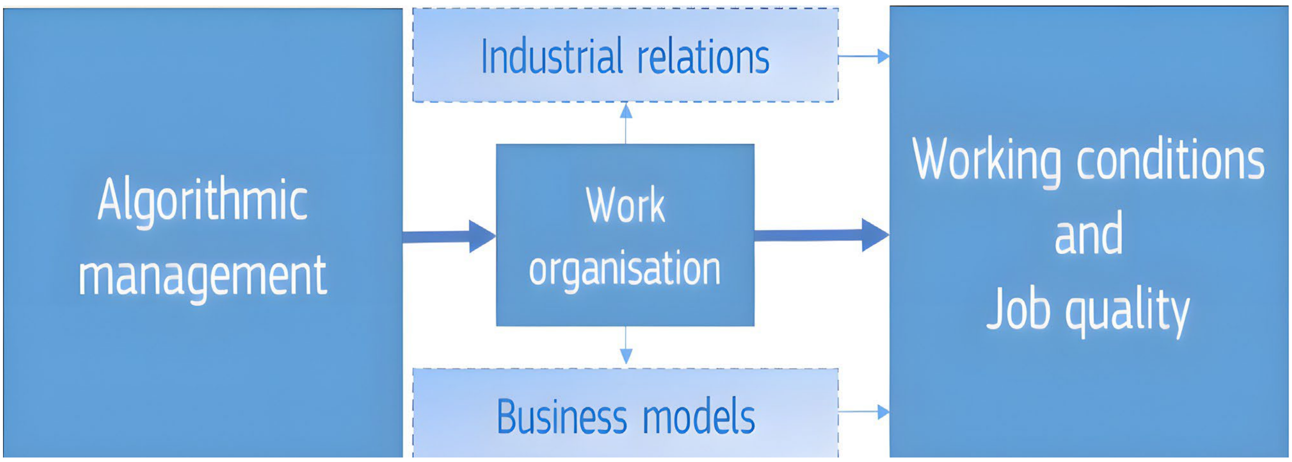


Figure 10. Implications of algorithmic management



Source: Baiocco et. al. 2022

> A key feature of algorithmic management is that it tends to standardise work processes, facilitating the contracting of labour input from outside the organisation. As algorithmic management spreads to the wider economy, it will likely extend at least some of these business practices to other sectors, segmenting value chains and transforming employment relationships.

The extent to which algorithmic management can negatively affect the level of control and discretion for workers, even low-level managers, is also an important source of concern. Combined with the information asymmetries potentially generated by massive data collection on work and production processes by algorithms for managerial purposes, algorithmic management can shift the balance towards managerial control in the power struggle in the workplace. This could be detrimental for workers suffering de-skilling and loss of control over their work.

Additionally, the inherent data collection potential of algorithmic management technologies poses a major challenge in terms of privacy and can lead to intrusive forms of worker monitoring and surveillance. Ultimately, algorithmic management – and its closely related and increasingly present cousin, digital monitoring – do seem to be implemented mostly following profitability considerations. They appear to be paving the way for a 'datafication' of work processes that enables firms to collect and leverage data and transform it into new forms of value (Zuboff 2019). These are strong indications that the implementation of these has an economic rationale (Schaupp 2022) and, in fact, proponents often argue that these practices improve business models, lead to productivity gains, enable a more efficient and effective coordination of work (Cirillo et al. 2022, Rani et al. 2024). As explained in chapters 2 and 4, a key underlying logic behind these practices is one of standardisation and bureaucratisation, leading to a consolidation of control in the workplace and centralising decision making at the highest layers of the organisation. As a result, this significantly alters labour processes, disrupting work organisation and the power balance in the workplace (Baiocco et al. 2022, Rani et. al. 2024). Overall, there is still a need to better understand this phenomenon and assess its pros and cons to inform future policy discussions on this complex and sensitive subject.

The platformisation of work: evidence from the JRC AMPWork survey

Given the potentially huge implications of these developments for the changing nature of work in Europe, our research has focused on better understanding the phenomenon. At the core of our studies is the concept of **'platformisation of work'**, which refers to the use of platforms and algorithms as mechanisms of coordination in regular workplaces beyond digital labour platforms, following the increase in digitalisation and connectivity at work (Fernández Macías et al., 2023). Indeed, Fana and Villani (2023) show that firms with higher level of digital (and process) innovation record higher levels of indirect control (especially related to algorithmic management).

The concept of platformisation of work in Fernández Macías et al. (2023) encompasses three distinct but closely related phenomena:

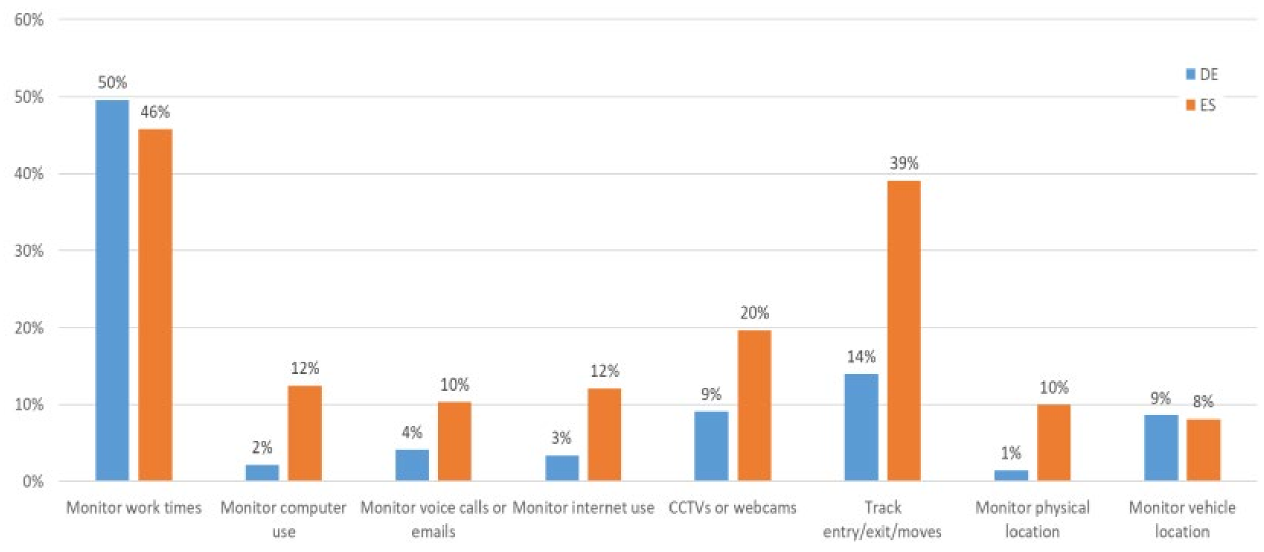
- firstly, the increasing use of digital devices at work, which represents the material base for the development of these practices,
- secondly, the rise of digital monitoring and surveillance,
- and thirdly, the use of algorithmic management.

This is the basic underpinning for the JRC Algorithmic Management and Platform Work survey (AMPWork), which represented in 2023 the first attempt to measure the prevalence of this phenomenon in Europe and assess its characteristics. AMPWork collected original representative data on the above three essential elements to understand the platformisation of work. The survey was conducted in Spain and Germany between September 2021 and March 2022, and is representative of the working age population (16-64) in these two countries. AMPWork shows that the material basis for platformisation is already well established: most workers (around two thirds) are already using digital devices in their daily work activities, and many of these devices are likely to incorporate platform-type software for the coordination of their input. It is nevertheless remarkable that still more than one third of respondents in both countries reported not using digital devices at work. Among those workers who report using at least one of the four types of digital tools, the most common device is a personal computer (PC) or laptop (55% and 56%, in Germany and Spain respectively).

Respondents using digital devices at work are often also subject to some degree of **digital monitoring**, according to their responses in the AMPWork survey. In particular, the survey reveals that the combined use of computers, mobile and wearable devices is strongly associated with the monitoring of work activities. AMPWork estimates show that the most common type of digital monitoring is the tracking of working times, followed by the use of swipe cards for tracking entry/exit/movements in the workplace and the use of devices to monitor vehicle locations and CCTVs or webcams (Figure 11).

AMPWork analysis shows that the eight simple types of monitoring observed in the figure can be combined into two underlying factors, which we name physical monitoring (meaning the monitoring of physical presence in the workplace) and activity monitoring (monitoring of activities carried out with digital tools). High levels of physical monitoring are found for operators, while it is relatively low for all of the other occupational groups. Activity monitoring is highest for clerks and professionals, and lowest for those in elementary, service, trades and agricultural occupations. The highest levels of monitoring and surveillance are found in High Technology Industries and Public Administration, for both activity and physical monitoring.

Figure 11. Use of digital tools for the monitoring of work



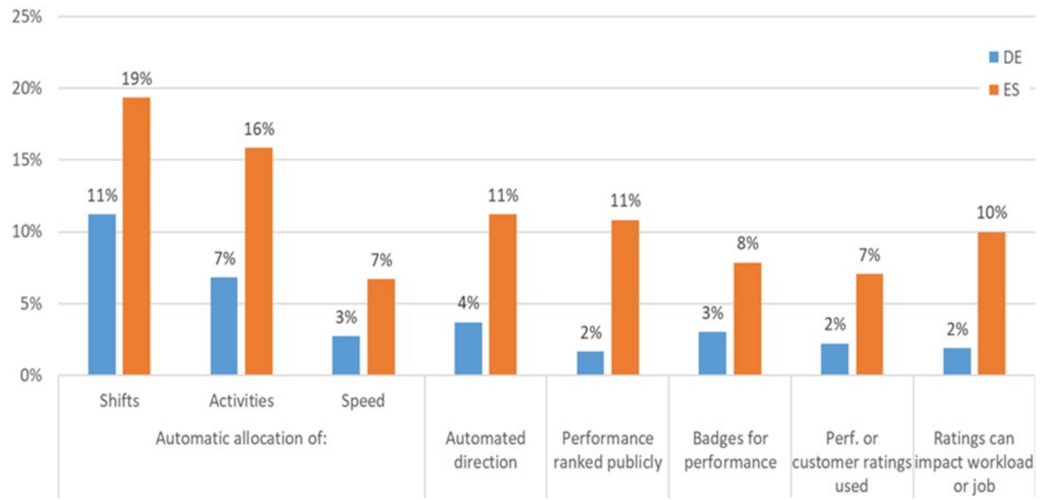
Source: Fernández-Macías et al. 2023

According to AMPWork, **algorithmic management** is much less common than digital monitoring, although not marginal. (Figure 12). Around one in five workers in Germany, and one in three in Spain, is subject to one or more automated systems of management, of which we identified two main types:

- algorithmic direction, where the algorithms provide instructions to workers,
- algorithmic evaluation, where the algorithms assess the performance of workers.

As shown in Figure 12, the automated allocation of work is the most widespread form of algorithmic management. More than 10% of German workers and almost 20% of Spanish workers are automatically allocated their shifts or working time via a digital device. Moreover, 7% and 16%, respectively, are allocated work activities via digital devices; 3% and 7% have the speed of their work determined by a digital device; and 4% of German workers and 11% of Spanish workers follow automated instructions or directions at work.

Figure 12. Indicators of algorithmic management



Source: Fernández-Macías et al. 2023

The highest levels of algorithmic direction are found among industrial plant and machine operators and assemblers, as could be expected. We also see surprisingly high levels of algorithmic direction in education. This might be linked to the increasing use of digital tools for education at all levels, which has been greatly accelerated by the Covid-19 pandemic. Algorithmic direction is also relatively high in high technology industries, health and knowledge intensive services; while it is lowest in the primary sector and in construction. As far as algorithmic evaluation is concerned, it is highest in high technology industries and knowledge intensive services. Managers have high levels of automated evaluation but very low levels of automated direction.

To assess the **incidence of platformisation**, we created four categories (Figure 13) based on the combined use of digital tools and the presence of algorithmic management, digital monitoring, or both:

- The first category (no use of digital tools and no platformisation) includes all those workers that use no digital tools at work and are not subject to either algorithmic management, nor digital monitoring.
- The second category (use of digital tools but no platformisation) includes those workers who use digital tools, but which are not under digital monitoring or algorithmic management systems.
- The third category (soft platformisation) includes those workers who use digital tools and are under mild forms of digital monitoring and algorithmic management.
- The fourth category (strong platformisation) includes those workers who use digital tools, and are under strong forms of both digital monitoring and algorithmic management, meaning that they are simultaneously under all the four main types of digital monitoring and algorithmic management.

Figure 13. Categories of platformisation of work

	DE	ES	Total
No digital	38.5%	34.6%	36.4%
Digital but not platformised	50.6%	41.3%	45.7%
Soft platformised	9.7%	18.0%	14.1%
Strong platformised	1.3%	6.1%	3.8%

Source: Fernández-Macías et al. 2023

Both soft and strong platformisation are found mainly among operators and clerks. High technology industries have the highest levels of both strong and soft platformisation, followed by knowledge intensive services. Interestingly, education comes third in the category of strong platformisation (although it is important to note that in general, the levels of strong platformisation are low).

As can be observed in Figure 14, in terms of **work organisation**, the analysis of the AMPWork data reveals that platformisation is associated with detailed procedures, problem-solving and complex activities, but not with time flexibility or autonomy. In other words, a complex work environment with an increased need to solve problems, but less resources to solve them. This reflects both a bureaucratisation of work as described in previous chapters, and heightened psychosocial risks for workers potentially leading to stress. In terms of **working conditions** outcomes, we do observe that platformisation seems to be associated with heightened stress, and also with less communication and greater monotony, again reflecting increased bureaucratisation and standardisation. Finally, with respect to location of work, 'platformisation' is stronger for those mainly working outside of their employers' premises, namely in a vehicle, at home, or in public spaces.

Figure 14. Platformisation of work by work organisation and working conditions outcomes

	Time flexibility	Detailed procedures	Problem solving	Complex activities	Autonomy index
No digital	-0,24	-0,22	-0,23	-0,34	-0,19
Digital tools, no AM	0,22	0,06	0,12	0,19	0,13
Dig soft DM & AM	-0,06	0,27	0,14	0,13	0,08
Dig strong AM & DM	-0,11	0,34	0,23	0,50	-0,06

	Can take break	Can communicate with superiors	Can communicate with peers	Stress at work	Job is monotonous
No digital	-0,17	-0,21	-0,22	-0,16	0,15
Digital tools, no AM	0,10	0,08	0,12	0,09	-0,20
Dig soft DM & AM	0,08	0,22	0,18	0,05	0,13
Dig strong AM & DM	0,14	0,18	-0,02	0,36	0,51

(Main place of work)

	Employer	Client	Vehicle	Home	Public space
No digital	-0,18	0,17	-0,03	-0,33	-0,04
Digital tools, no AM	0,15	-0,09	-0,09	0,18	-0,01
Dig soft DM & AM	0,04	-0,12	0,18	0,18	0,11
Dig strong AM & DM	-0,21	-0,06	0,59	0,33	0,10

Source: Fernández-Macías et al. 2023

An evolving and expanding reality

A recent qualitative study, conducted by the JRC in collaboration with the ILO, investigates the application of algorithmic management practices in regular workplaces in the logistics and healthcare sectors. The picture that emerges is broadly in line with the one depicted in the studies on automation in services and in manufacturing described in chapter 3. This emerging body of evidence confirms that algorithmic management is already a reality, and indeed a growing one, but also far from homogeneous: similar technologies have very different effects across sectors and countries. At the same time, in all cases we do observe some common patterns, in particular pervasive digitisation and relevant digital monitoring and algorithmic management practices that imply risks for workers (Cirillo et al. 2022, Fana et al. 2024, Rani et. al. 2024).

The research was conducted in 2022-2023 in two highly developed European countries (Italy and France) and two developing non-European countries (India and South Africa), looking at both general-purpose digital technologies and specific-purpose ones. A common element to all these tools is that they are implemented and driven by the objective to maximise profit, increase productivity, improve the business model or foster efficiency gains. The technologies studied generally seemed to have a positive impact on productivity and efficiency through a simplification and streamlining of work processes.

Another crucial point common across all sectors and countries is that all analysed technologies create the conditions for a centralisation of knowledge and control. As they facilitate the collection of a wide range of data to control and monitor workers, they could potentially shift the power balance within the organisation towards management, although this does not seem to have materialised yet. However, the potential for data collection and processing and the evidence that such data (e.g. on productivity of workers and their work schedules) is already being used and analysed by managers while remaining largely inaccessible to workers, illustrates the risk that further reinforcement of the power of management could materialise in the future, affecting workers negatively (Rani et. al. 2024).

Indeed, the analysed technologies create the conditions for increased monitoring and surveillance of workers, with the possibility to check their performance and measure it against pre-determined, algorithmically created benchmarks. In Europe regulatory safeguards appear to be preventing a major impact for the moment, while in South Africa and India worker monitoring and surveillance is already intense and intrusive. While in some cases, particularly in public organisations in the healthcare sector, evidence shows a positive or neutral impact on working conditions and job quality in Europe, there are also some negative repercussions that deserve close attention and further research. Centralised algorithmic control in the cases analysed in Europe has not directly led to a reduction of working time quality, but the technologies potentially lead to work intensification which, in turn, is clearly observed in the non-European cases. In fact, in the non-European cases the deterioration of working conditions is clearly visible. In Europe, the data collected and monitored does not seem to be used yet for worker evaluation, while this is clearly already the case in South Africa and India (Rani et. al. 2024). The study also analysed worker consultation and the role of collective bargaining in decisions concerning technology adoption and implementation, and an important common element observed was the low level of involvement of trade unions in the decisions concerning technological change. In general, the consultation with workers in adopting digital technology and automation in both sectors has been very limited across countries.

Overall, there is a striking contrast between the impact of these technologies in the European and the non-European cases. The case studies conducted in Italy and France show benefits in terms of work coordination and improvements in the business models without pervasive negative consequences in terms of job quality, and also without visible excesses in terms of monitoring and surveillance of workers. In the case studies conducted in India and South Africa the situation is very different. With similar technologies and similar types of work, in these cases we also see productivity and efficiency gains as well as improvements in business models, but we do observe also a significant worsening of job quality and, importantly, clear evidence of very intrusive forms of worker monitoring and surveillance, including with disciplinary consequences.

This striking contrast implies that the impact of algorithmic management in the workplace in traditional sectors appears to be mediated by the institutional and the regulatory framework in place. The degree of unionisation, the more advanced employment regulation and the share of public employment also seem to play an important role in mitigating negative consequences.

5.3 Key findings and conclusions

Overall digital technologies continue to have a big effect on work and employment in Europe. This effect is mostly materialised in a changing nature and organisation of work. However, the way through which these impacts affect work and employment evolve over time, and therefore requires close monitoring and a long-term research agenda to ensure a good understanding of a dynamic and constantly shifting situation.

When the JRC started analysing digital labour platforms in 2017, these were still largely considered as online collaborative tools with limited impact on work. Over time the growth and consolidation of platform work in Europe has transformed it into a marginal and consolidated form of work that is no longer recent or novel, and that is subject to close public and regulatory scrutiny. In the last few years JRC research has studied this process, trying to better understand its broad-ranging implications, which allowed us to identify the expansion of key features of digital labour platforms, such as digital monitoring and algorithmic management, into standard workplaces. Our research shows that the material basis for platformisation is already well established, confirms that using digital devices at work often leads to some degree of digital monitoring, and reveals that algorithmic management, while less common than digital monitoring, is not marginal. We also observe that platformisation can lead to stress, less communication and greater monotony, reflecting increased bureaucratisation and standardisation.

Qualitative research increasingly points in a similar direction, with case studies revealing that the conditions for intrusive monitoring and for a deterioration of job quality already exist, with labour market institutions playing a crucial role in mitigating these effects. We also see how the original concept of algorithmic management is mutating. Our most recent research shows that there is a very wide range of technologies, including even general-purpose technologies such as instant messaging tools or text editing software, that can be used to manage and coordinate work and collect worker data. We see that the use of technologies for work management functions need not be explicit or even intentional in order to have direct consequences in terms of work organisation, working conditions and industrial relations. In many cases, the technologies we have analysed have relevant implications in these regards even if they are not directly intended to be used for work coordination. Indeed, algorithmic management is often a kind of unintended result of using digital process management tools in a broader sense. This means that, even if these algorithmic systems are not explicitly intended to manage work processes, de facto they can be considered as part of, or at least equivalent to, algorithmic management systems.

Therefore, it appears necessary to consider a revised and expanded definition of algorithmic management, going beyond the use of algorithmic management for the explicit purpose of coordinating work processes, to including any type of algorithmic system with implications for the organisation of work within the workplace. This implies that the concept of algorithmic management may be too narrow as it cannot be strictly confined to the use of algorithmic tools used for the coordination of work. Instead, it needs to be broadened to include the use of a wide range of digital tools with implications for the organisation of work within the workplace, including for instance systems of monitoring and surveillance of workers. This is the rationale behind the “platformisation of work” concept coined by the JRC, which encompasses the material base (use of digital tools), its implications in terms of data collection and worker monitoring, and its algorithmic management features.

What comes next? The question, which is always pertinent, has recently acquired even more relevance with recent advances in AI and the potential implications of the application of large language models to different purposes in the work context. While it is too early to assess these impacts, there does appear to be strong potential for these tools to enhance the positive features of technologies in the workplace in terms of improving business models, facilitating the coordination of work and leading to productivity gains. Some preliminary or anecdotal evidence of AI-powered algorithmic management technologies point in this direction. At the same time, these technologies can amplify the potentially negative implications for workers in terms of de-skilling and loss of autonomy, exacerbating also the potential for intrusive worker monitoring and surveillance.

As previously argued, the outcomes of technology at work are far from predetermined and instead can be shaped by regulations and labour market institutions. Bailey (2022) argues that the technological outcomes are not hardwired and can be shaped by human choice and agency, an insight that cuts across all research findings in our programme over the last few years. It is clear that the changes in the nature of work stemming from digital technologies have important policy implications in Europe and beyond. The empirical evidence provided by the JRC on digital labour platforms, algorithmic management and platformisation of work will be conceived to support policy, particularly through the forthcoming AIM-WORK survey data which applies the approach followed in AMPWork in a large pan-European survey representative of the working age population in all EU Member States.

OCCUPATIONAL CHANGE

Occupational change refers to the analysis of changes in the levels of employment across different occupations in a specific place and period. It involves examining in which occupations employment growth and losses have been concentrated, categorised by job quality level.[13] As such, it is a topic with broad social, political, and economic implications and that has garnered attention from social scientists for a very long time. However, this debate gained greater prominence since the 1970s, with contributions from authors such as Daniel Bell (1973) and Harry Braverman (1974), who were interested in the implications of the transition from industrial to post-industrial societies and the impact of technology on labour. A significant advance was made in the 1990s, when approaches and methods of occupational analysis were fine-tuned and systematised, laying the foundations for the emergence of comparative studies on the subject.

At least since then, the debate has been linked to the notion of job polarisation, that describes a phenomenon in which employment growth is concentrated at both extremes of the occupational distribution, meaning that employment grows faster in high- and low-quality jobs than in mid-quality jobs. The opposite can also happen, where employment growth is faster in mid-quality jobs, a phenomenon known as middling. Job upgrading occurs when employment growth is skewed toward high-quality jobs. This implies that the higher the quality of jobs, the faster the employment growth. The opposite of job upgrading is downgrading, where employment growth is concentrated in low-quality jobs.

13 The quality of jobs or occupations is commonly assessed in the specialized literature using various highly correlated proxies, including wages (which we primarily rely on), workers' educational attainment, and other non-pecuniary or multidimensional indices. Generally, higher wages, educational attainment, or similar indicators are associated with higher job quality. For more information on the differences in results when using different measures and their correlations, see Annex 3 in Fernández-Macías et al. (2017).

Obviously, all the aforementioned patterns have broad socio-economic implications. In the labour market, these processes impact the potential to create high-, mid-, and low-quality jobs, thereby influencing both employment rates and upward or downward labour market transitions. Economically, employment restructuring can drive shifts from agricultural or industrial societies toward service-based economies or lead to different economic and sectoral configurations. At a societal level, employment shifts affect social cohesion and political preferences, as they influence job quality, social status dynamics, and the distribution of life chances in society at large. In summary, considering these and other potential implications, it becomes clear why studying patterns of occupational change is crucial for various disciplines and policymakers.

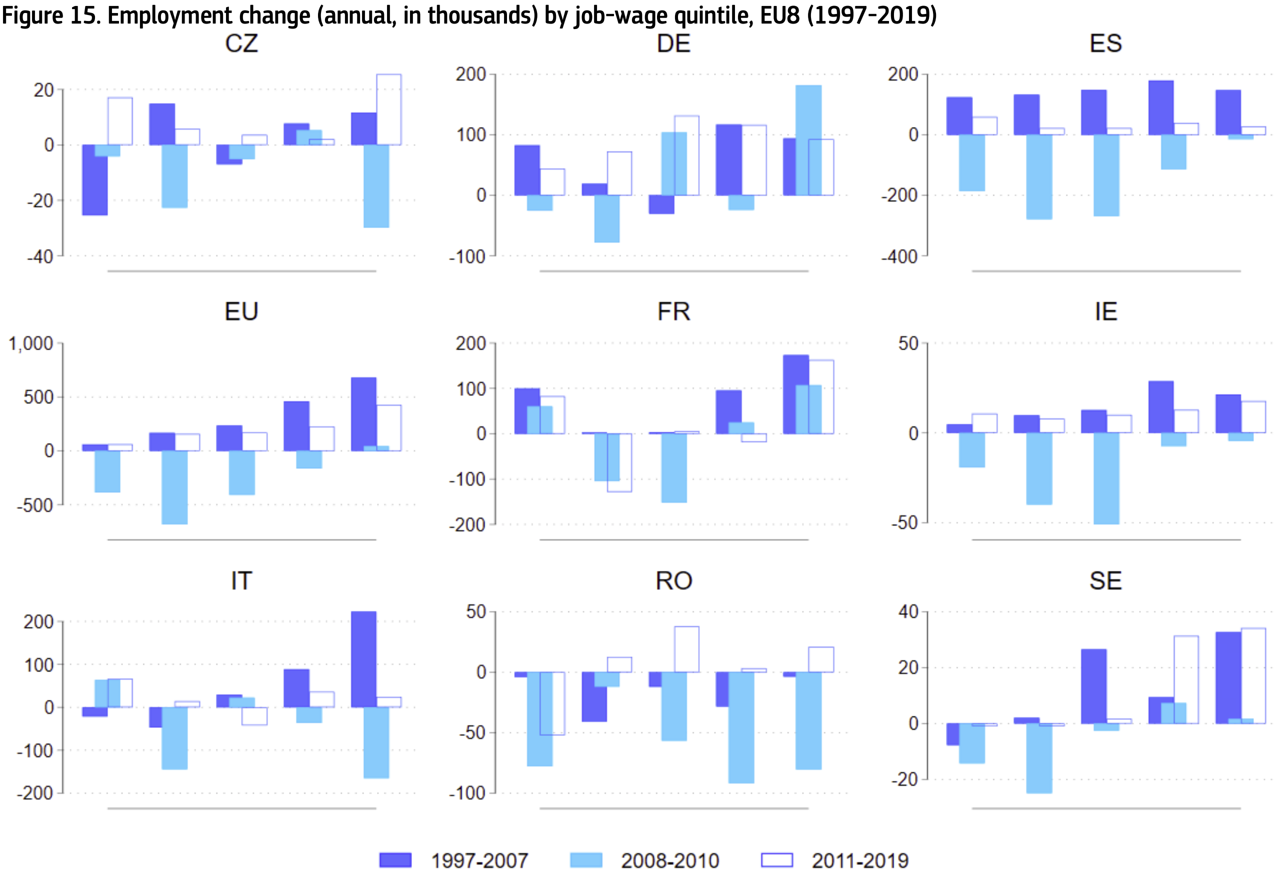
While the debate on occupational change has long been linked to job polarisation, there is a growing body of literature presenting more nuanced perspectives, including our own contributions. First, new research challenges the notion of a uniform pattern of occupational change across different countries and time periods, highlighting instead a diversity of employment trends. Second, an increasing number of studies find patterns of job upgrading or others, suggesting a more complex landscape of occupational shifts. Additionally, regional evidence has supplemented the extensive research initially conducted at the national level, indicating that significant differences are also found within countries. This line of research indicates that, generally speaking, there has been some convergence of occupational structures across regions within countries in the EU. However, key differences persist, with most employment growth concentrated in capital regions and large cities and job polarisation more likely to happen in these more innovative regions. In the following pages, we summarise our contributions to the field, aiming to provide a reliable and well-rounded understanding of a phenomenon that has garnered considerable interest in the domain of the social sciences and in the public debate.

6.1 From job polarisation to upgrading: evidence at the national level

Most of the initial studies on occupational change applying modern and potentially comparative methods focused on the United States (US), which has come to be known as a paradigmatic example of job polarisation (CEA 1996; Wright and Dwyer 2003; Autor et al. 2006). Since then, the specialised literature has been largely influenced by these early studies, replicating similar approaches and methods, thereby expanding similar diagnoses to other cases (Goos and Manning 2007; Goos et al. 2009, 2010, 2014). As a result, the concept of job polarisation has become recurrent in the literature. According to this body of work, the relatively higher expansion of low- and high-quality jobs compared to mid-quality jobs has been a common trend due to the impact of new technologies and international trade on advanced economies' labour markets.

But as more comparative studies were carried out, particularly in Europe, the picture became more diverse. Several cross-country analyses, including our own contributions, found no pervasive pattern of occupational change across countries and periods, but a variety of patterns across countries (Hurley and Fernández-Macías 2009; Oesch and Rodríguez Menés 2011; Fernández-Macías 2012; see Figure 15). Since then, in the last decades a large body of literature supporting this idea has been published, both in the context of Europe (Fernández-Macías et al. 2017; Oesch 2015; Hurley et al. 2021; Torrejón Pérez et al. 2023) and at a global scale (Torrejón Pérez et al. 2025).

Figure 15. Employment change (annual, in thousands) by job-wage quintile, EU8 (1997-2019)



Source: Torrejón Pérez et al. (2023) based on EU-LFS and SES data. Note: quintiles are defined separately for each period.

> Our findings suggest that job upgrading, broadly speaking, has been the most common type of occupational change. This indicates that in recent decades, employment growth has predominantly concentrated in high-quality jobs.

While most studies have focused primarily on the impact of technological change and international trade, comparative evidence has prompted researchers to consider additional factors that also influence employment dynamics and had previously been overlooked. Many of these factors are country-specific, such as institutional settings, the sociodemographic composition of the workforce, migration flows, and others. Because these factors vary by country and interact differently in each context, a variety of patterns across countries can be expected. As a result, the notion of job polarisation as a pervasive trend has been increasingly challenged and considered to be overly reductionist. Perspectives and studies that account for a broader set of drivers and factors, rather than just one or a few, are now advancing the debate.

The policy implications are clear. Since no single pattern of employment change prevails and no single driver explains all observed changes, there cannot be a one-size-fits-all strategy to prevent job polarisation or to promote high quality employment creation. On the contrary, employment policies must consider how the various factors influencing employment dynamics are configured and behave in each specific context. In-depth, country-specific studies, and studies that use comparable methods, are therefore greatly needed. However, as is often the case, nuanced perspectives have long been overshadowed by eye-catching headlines that are more prone to hype. We hope that the new findings and insights presented here and related publication serve to enrich the debate and reintroduce more nuanced and realistic views into the discussion.

Job upgrading prevails in the 21st century

Within the variety of patterns of occupational change across countries, recent evidence suggests that at a global scale, in the first decades of the 21th century the most common pattern of occupational change has been job upgrading, rather than job polarisation. This has been documented in Europe (Torrejón Pérez et al. 2023; Fernández-Macías et al. 2017; Hurley et al. 2021; Oesch and Piccitto 2019; Albertini et al. 2020) and outside Europe for a selection of developed and developing countries (Torrejón Pérez et al. 2025; Willcox and Feor 2023; Rodrigues Silveira 2023; Maurizio et al 2023; Gimpelson and Kapeliushnikov 2023; Sarkar and Torrejón Pérez 2023). As shown in Figure 16, job upgrading prevailed in the long term at least in Germany, Ireland, and Sweden, as well as in the EU8 as a whole. By EU8, we refer to the aggregate trends of the eight countries covered in this study: the Czech Republic, Germany, Spain, France, Ireland, Italy, Romania, and Sweden. In contrast, from these eight countries, job polarisation has consistently been observed only in France. Outside of Europe, according to a large study covering seventeen of the world's largest economies, representing more than one third of total global employment (Torrejón Pérez et al. 2024; 2025), countries where job upgrading (or variants of this pattern) have been registered in the long run include Canada, Mexico, Chile, Argentina, Russia, and India, while job polarisation is only found in the US and South Korea.

In summary, although patterns of change vary across countries and time periods (and may differ slightly in pace and form)[14], recent findings suggest that job upgrading, broadly speaking, has been the most common type of occupational change. This indicates that in recent decades, employment growth has predominantly concentrated in high-quality jobs. The general outlook on occupational change is therefore rather optimistic: in many countries, employment structures are improving, with a growing number of jobs offering better quality than those that

14 In some Latin American countries, the most commonly observed pattern aligns more closely with mid-upgrading, a variation of upgrading where employment growth is more skewed toward mid to high-paid jobs (Maurizio et al. 2023).

existed previously.[15] As we show below, this trend is often linked to tertiarisation and feminisation of employment, and with general economic progress.

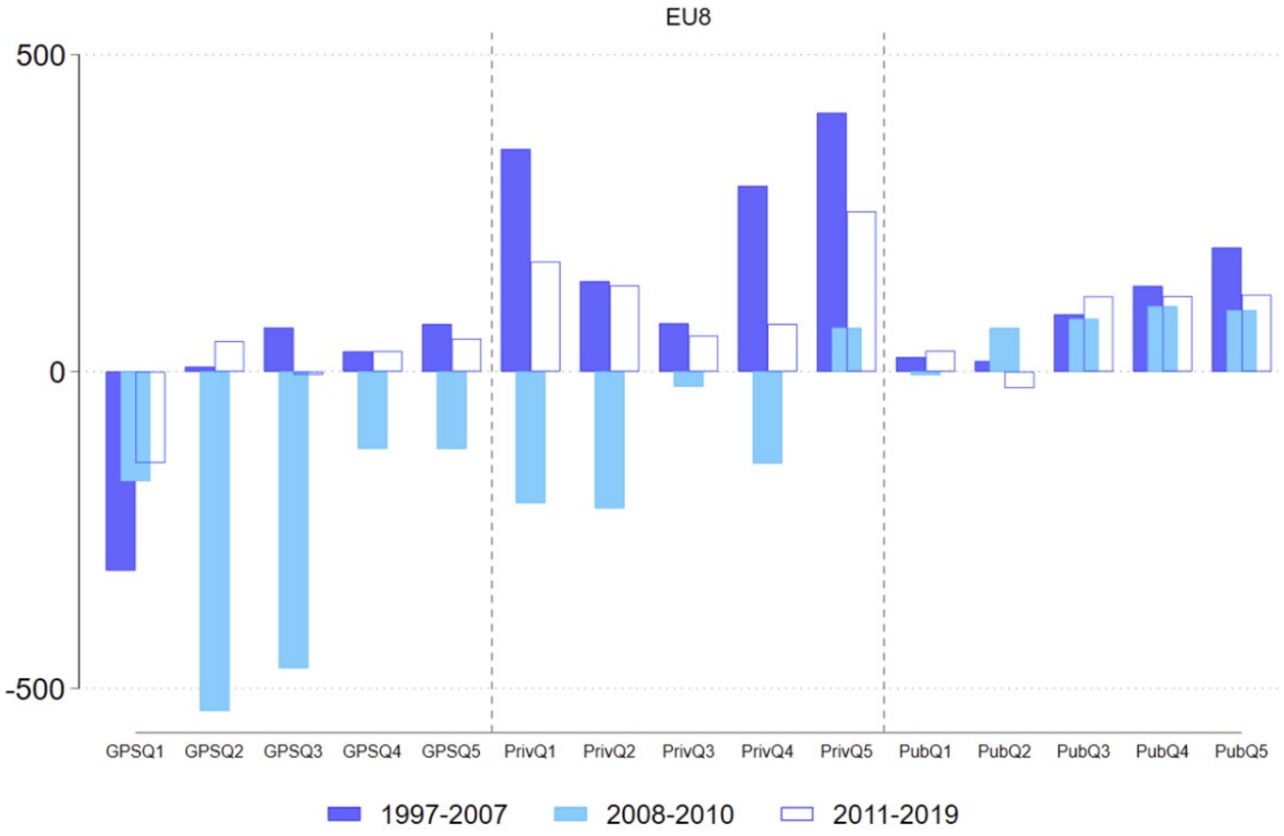
Private services grow polarised, public services grow by job upgrading

A sectoral perspective is crucial to understand why job upgrading is so prevalent in many countries over the long term. High-paying and high-quality jobs are expanding partly due to the growth of the service sector. In all countries, employment in the goods-producing sector (which includes agriculture, mining and quarrying, construction, manufacturing, and utilities) has been declining, reflecting processes of deagrarianisation and deindustrialisation. In contrast, employment in services, where best-paying jobs tend to be located, has consistently grown over the past decades, demonstrating a long-standing trend toward tertiarisation.

As Figure 16 shows, between 1997 and 2019, most employment growth in the EU countries analysed in this study (the Czech Republic, Germany, Spain, France, Ireland, Italy, Romania, and Sweden) occurred in private services. This was followed by growth in public services, while the goods-producing sector experienced net employment losses. In other words, private services were the primary driver of employment growth in these countries, with public services also making a significant contribution. Although these are aggregate trends for the eight aforementioned countries, the main sectoral patterns hold in most countries of the sample individually.

15 However, job upgrading cannot be considered a positive outcome by default. While employment growth may be higher in higher-wage jobs, this can occur without net employment creation. If job losses in lower quintiles exceed job gains in higher quintiles, a significant portion of the workforce may transition to unemployment or inactivity. This would represent a scenario where job upgrading occurs, but the situation for many workers does not improve at all. Therefore, it is crucial not only to focus on the shape of employment change patterns but also to consider whether net employment growth is positive or negative, and whether it matches the evolution of the working age population.

Figure 16. Annual employment change by quintile and sector, EU8, (1997-2019)



Source: Torrejón Pérez et al. (2023) based on EU-LFS and SES data.
Note: Changes in thousands; quintiles are defined separately for each period; 'GPS' = goods producing sector; 'Priv' = private services; 'Pub' = Public services

Although all types of services have been driving employment growth in the EU, it is important to distinguish between private and public services in terms of their particular pattern of growth. While private services often exhibit polarised growth (particularly during periods of economic expansion), employment growth in public services tends to be concentrated in high-quality jobs, thus promoting job upgrading. This is because private services encompass both professional or technical work and lower-paid jobs, such as personal or care service work. In other words, within this broad and expanding category, there are jobs with significantly different wages, working conditions, and qualifications. In contrast, most jobs within the public service sector tend to offer wages and require qualifications above the average. In this regard, Figure 16 illustrates how, in the EU countries analysed, employment growth in private services during periods of expansion has been concentrated at both extremes of the wage distribution (quintiles 1, 4, and 5, indicating a polarizing trend), whereas employment growth in public services, across all sub-periods, has been concentrated in top-paying jobs (quintiles 4 and 5). Although we present evidence for the EU, similar sectoral trends have recently been documented in other countries outside the EU (Torrejón Pérez et al., 2025).

Figure 16 also suggests that employment change was faster during the expansive phase of the business cycle preceding the global financial crisis (1997-2007), particularly in private services. During the Great Recession (2008-2010), there was also rapid employment change, marked by net employment losses in the goods-producing sector and in private services, alongside net employment gains in public services. This combination explains why the period was characterised by rapid restructuring. However, after the Great Recession (2011-2019), the pace of employment change slowed. While there were net employment gains again (mainly in services), these occurred at a slower pace than in previous periods. This highlights that, overall, the pace and intensity of structural change were much higher in the two sub-periods before 2011 than in recent years. Why has change not been as rapid recently, despite being in an era of rapid technological and socio-economic transformations? This is a question that requires further exploration and constitutes an interesting avenue for future research.

> "Not only do we observe various patterns across different countries, but also across regions within the same country"

6.2 Occupational change at the regional level

The analysis of structural employment changes at the country level often obscures highly heterogeneous employment dynamics across regions within the same country. Despite the extensive evidence at the national level, little is known about changes in occupational structure across regions. Only in recent years have researchers begun to utilise datasets and develop new procedures that allow for the analysis of occupational change at this more granular level.

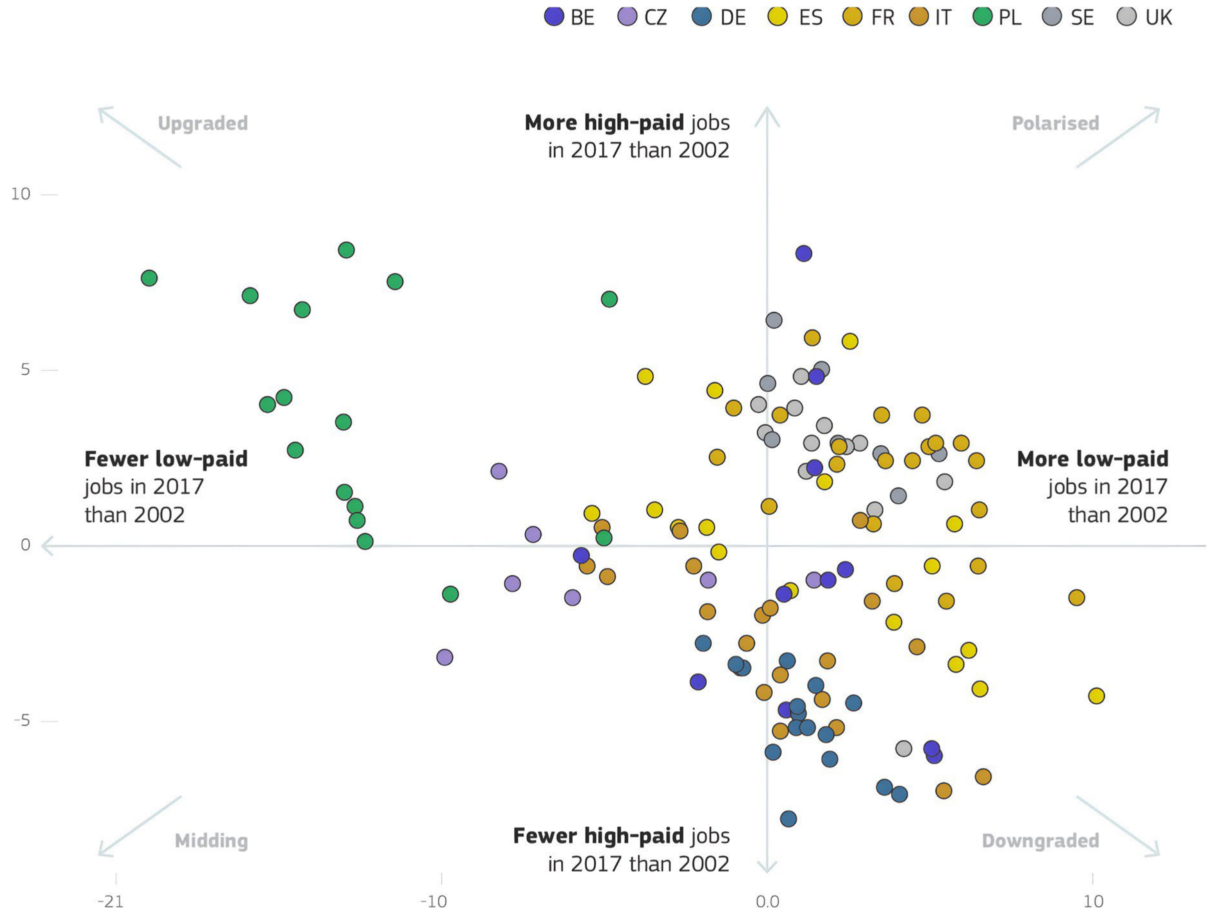
This emerging literature suggests that the diversity of occupational change patterns extends from the national to the regional level. Not only do we observe various patterns across different countries, but also across regions within the same country. Beyond this, three additional key lessons can be drawn from these studies: first, there has been some convergence in employment shares between regions within countries over the last few decades; second, despite this convergence, good jobs still concentrate in central and innovative regions (such as capital regions) while bad jobs tend to concentrate in peripheral areas; and third, job polarisation is more likely to occur in capital city regions and innovative areas.

Occupational change also varies by region

In 2019 the JRC and Eurofound made an innovative contribution by extending occupational change analysis to the regional level in the EU (Hurley et al. 2019). This study for the European Jobs Monitor analysed employment shifts from 2002 to 2017 for a sample of 130 regions across 9 European countries,[16] representing around two thirds of the population employed in what was the EU-28 back in 2018. In this study, the EU-9 average employment structure (that includes also the United Kingdom, see footnote 16) was set as a common benchmark against which regional employment structures and shifts over time could be assessed. Its main findings (Figure 17) are:

16 The sample consists of Belgium, Spain, Poland, Czechia, France, Sweden, Germany, Italy, and the United Kingdom, which was still a member of the European Union in 2019 when the report was published.

Figure 17. Regional employment changes relative to the EU-9 average (2002-2027)[17]



Source: JRC and Eurofound calculations (Hurley et al. 2019) based on EU-LFS data

5. On average, changes in the occupational structures in different regions tend to be similar to those of their respective countries, with some exceptions.

6. Around one third of the regions analysed experienced greater job polarisation than the EU benchmark. Between 2002 and 2017, job polarisation was observed across most regions in France, the UK and Sweden, as well as several Spanish ones. The main underlying trend in many of these regions was a decline in middle-paid manufacturing jobs which was offset by growth in both high- and low-paid ones in the service sector.

- Occupational upgrading occurred mainly in Spanish and Polish regions, where the number of low-paid jobs decreased, and middle- and high-paid jobs became more prevalent. This improvement is largely the result of declining agricultural employment, which has been compensated primarily by growth in mid- and high-paid jobs in services and manufacturing. Nevertheless, the share of employment in agriculture, and the share of low-paid jobs, remains significantly higher in these fast-converging regions than in most other regions.

- In several regions, the employment structure downgraded. From 2002 to 2017, regions in Germany and Italy, as well as some in Spain, witnessed a reduction in the share of high-paid jobs, combined with growing shares of middle- and low-paid jobs. This trend was driven by regions with intermediate population density,

17 The horizontal axis shows by how much the percentage point difference between the share of low-paid jobs (lowest tercile) in the region vis-à-vis the EU-9 average (approximately 33.3 %) in 2017 changed when compared to 2002. The vertical axis indicates by how much the percentage point difference between the share of high-paid jobs (highest tercile) in the region vis-à-vis the EU-9 (again, approximately 33.3 % by construction) in 2017 changed relative to 2002.

where fewer jobs in high-paid sectors have been compensated for by the expansion of mid- and low-paid employment.

- Only few regions witnessed a growing concentration of employment in the middle of wage distribution (middling). In a small fraction of the regions (mostly in Czechia, Italy and Germany) middle-paid jobs expanded faster than low- and high paid ones. In some cases, such as in Czechian regions, growing shares in middle-paid jobs resulted mainly from employment shifting away from low-paid jobs, and was only marginally due to shrinking shares of high-paid employment. Conversely, the process of middling across German and Italian regions was mostly driven by employment shifts from high- to middle-paid jobs, a pattern resembling occupational downgrading rather than middling.

This study reveals that, in the 9 European countries analysed, there is greater variation in patterns of employment restructuring across regions than across countries. The main implication is clear: when examining evidence at the regional level, the notion of a single pervasive pattern of occupational change (namely job polarisation) becomes even more disputed.

Convergence across regions within countries

Although there is a wide variety of patterns of employment restructuring across EU regions, a recent study indicates that regional patterns within countries are converging. Vera-Toscano et al. (2022) find there has been some degree of convergence in the regional occupational structures of six EU countries (Spain, Portugal, Greece, Ireland, Austria, and Romania) over 1981-2011.

By using census data, the study examines the variability in employment shares by terciles of job quality[18] across all regions within each country, as detailed in Figure 18.

They first see a significant decline in the level of dispersion of regional employment shares within each tercile over time. This indicates that the occupational structures of the regions became more similar to the national average, suggesting a general trend toward convergence in regional occupational structures within countries.

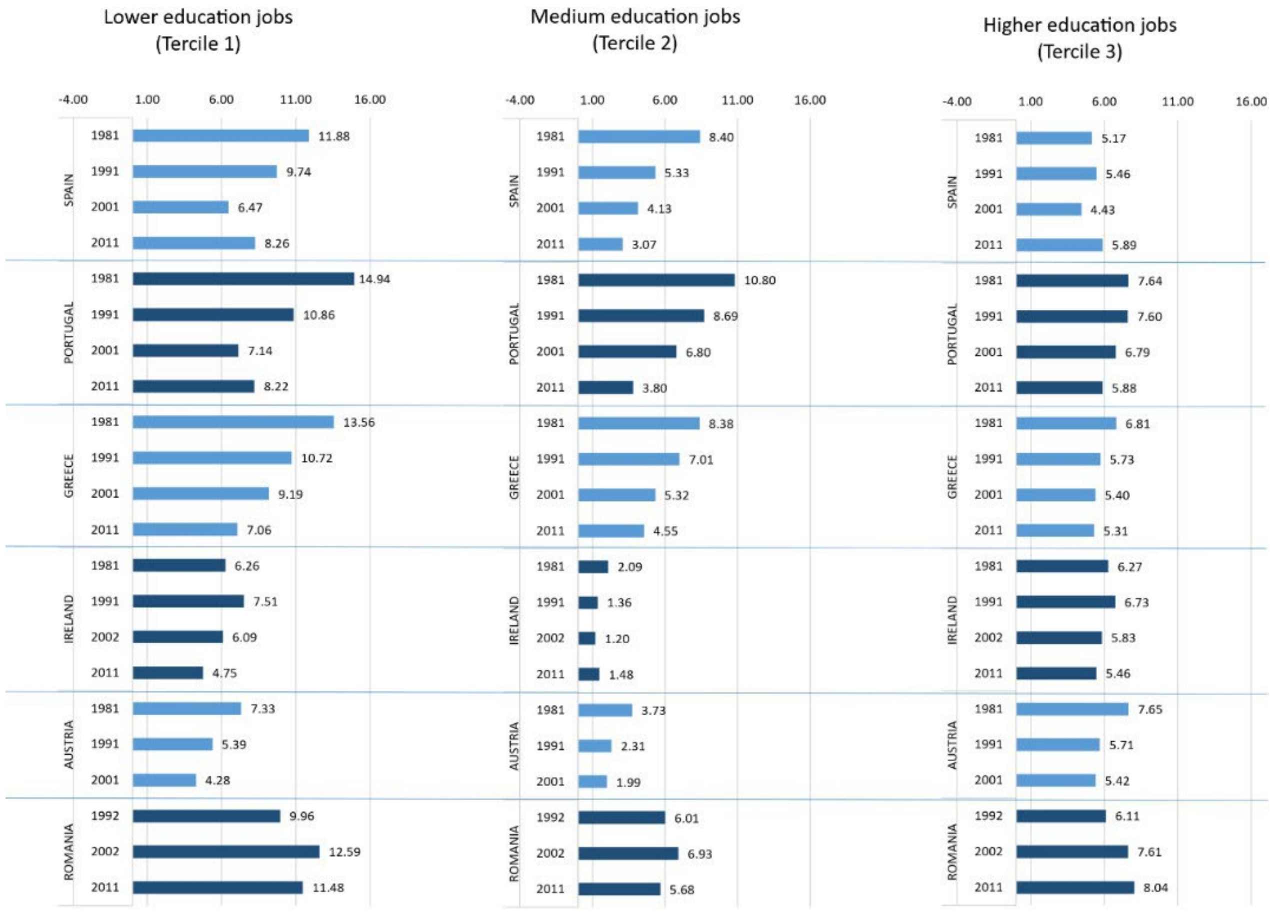
Divergences in employment shares by terciles between regions are higher in terciles 1 and 2, meaning there is generally more regional variability in the shares of low and mid-quality jobs. In other words, regions differ more in their shares of employment in low- and mid-quality jobs than in high-quality jobs. While some regions have a high concentration of low-quality jobs and others have very few, most regions have a similar share of high-quality jobs. This confirms, with regional-level evidence, that high-quality jobs have expanded in most regions and countries over the last few decades. This expansion has mainly been driven by the expansion of tertiary education (i.e. a change in the labour supply) as well as tertiarisation, technological change, and international trade (i.e., widespread changes in labour demand). However, the specific pattern of occupational change observed in each place is largely determined by employment dynamics at the lower half of the wage structure.

Employment trends in low-quality jobs are particularly influenced by the institutional setting, regulations, and policies. This is why we believe that, beyond technology, international trade, and other global trends, institutions, regulations, and policies are also crucial for understanding why job polarisation occurs in a given place or not, as has previously been argued (Maarek and Moiteaux 2021; Fernández-Macías et al. 2017). Studies that focus only on a few factors and global trends are likely to miss the full picture and may be unable to explain why patterns of occupational change take different shapes.

However, most of the convergence in regional occupational structures occurred because regions became less diverse in their share of employment in low- and mid-quality jobs. While in the past, regions differed significantly in the lower half of their occupational structures, these differences have diminished over time. This process has been more pronounced in Spain, Portugal, and Greece, countries that joined the EU relatively late, had sizable agricultural sectors in the 1980s, and underwent delayed modernization and economic restructuring from the 1980s to the early 2000s. In this period, they experienced significant declines in agricultural and manufacturing employment, along with

18 Tercile 1 represents approximately one-third of total employment with lower quality (where workers with lower educational attainment are employed), while Tercile 3 represents one-third of total employment with higher quality (where workers with higher educational attainment are employed). Tercile 2 occupies an intermediate position.

Figure 18. Regional convergence across terciles by decade and country



Source: Vera-Toscano et al. (2022).
Note: as reported by standard deviations, calculated using the regional values of the share of people employed in each tercile for each year

increases in public and private service sector jobs. In short, these are countries that underwent delayed economic modernization compared to other EU nations.

Among the factors producing regional convergence within countries over time, we should mention sectorial trends that are, to some extent, shared across developed countries:

- The decline in agricultural employment, which has led to a reduction in low-quality jobs in some less developed regions, and especially in Spain, Greece and Portugal.

- A less advanced but still significant process of deindustrialisation, which has resulted in net declines in mid-quality jobs in many traditionally industrial and affluent non-capital regions. Where there have been more employment losses in manufacturing, there has also been more polarisation. This polarising deindustrialisation has been strongest in some regions of Romania and Spain, followed by Greece, Portugal and Ireland.

- The continued expansion of public sector jobs, which, particularly in less developed regions, has driven the growth of high-quality employment.

However, although the degree of regional occupational differentiation within countries is smaller than it was in 1981, it remains significant. Capital regions concentrate a disproportionate share of high-quality jobs, while others (especially rural areas) continue to hold most low-quality jobs. In fact, this unequal distribution has been exacerbated by the decline of industrialized regions, which once concentrated large shares of mid-quality jobs. The next section delves deeper into this and presents more details on the regional distribution of jobs.

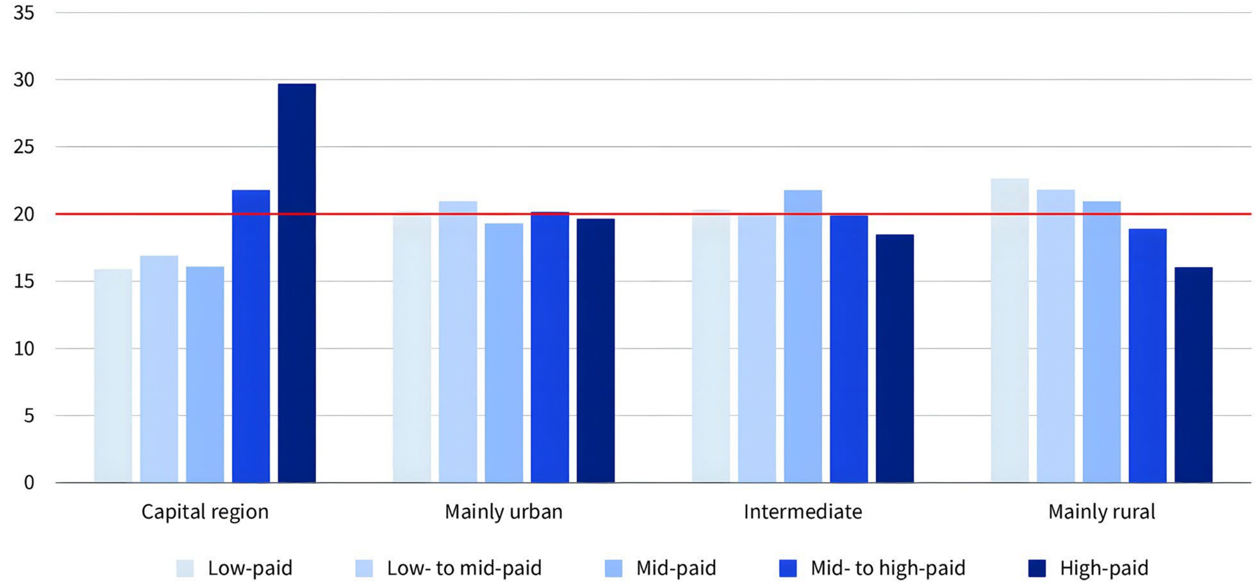
Urban and rural patterns of occupational change

Although there has been some degree of regional convergence within countries, Hurley et al. (2019) and Bisello et al. (2024) confirm that notable differences across EU regional employment structures still remain.

At the aggregate level in Europe,[19] capital regions have a significantly larger share of high-paid jobs compared to others, as seen in Figure 19. On the other hand, the prevalence of low-paid jobs is higher outside capital regions, and especially in rural areas.

19 In a sample that consist of 21 EU countries, that is all EU countries but Cyprus, Estonia, Latvia, Luxembourg, Malta and the Netherlands.

Figure 19. Percentage of employment by job-wage quintile and region type, Europe (2019)
Source: Bisello et al. (2024) based EU-LFS and SES data.

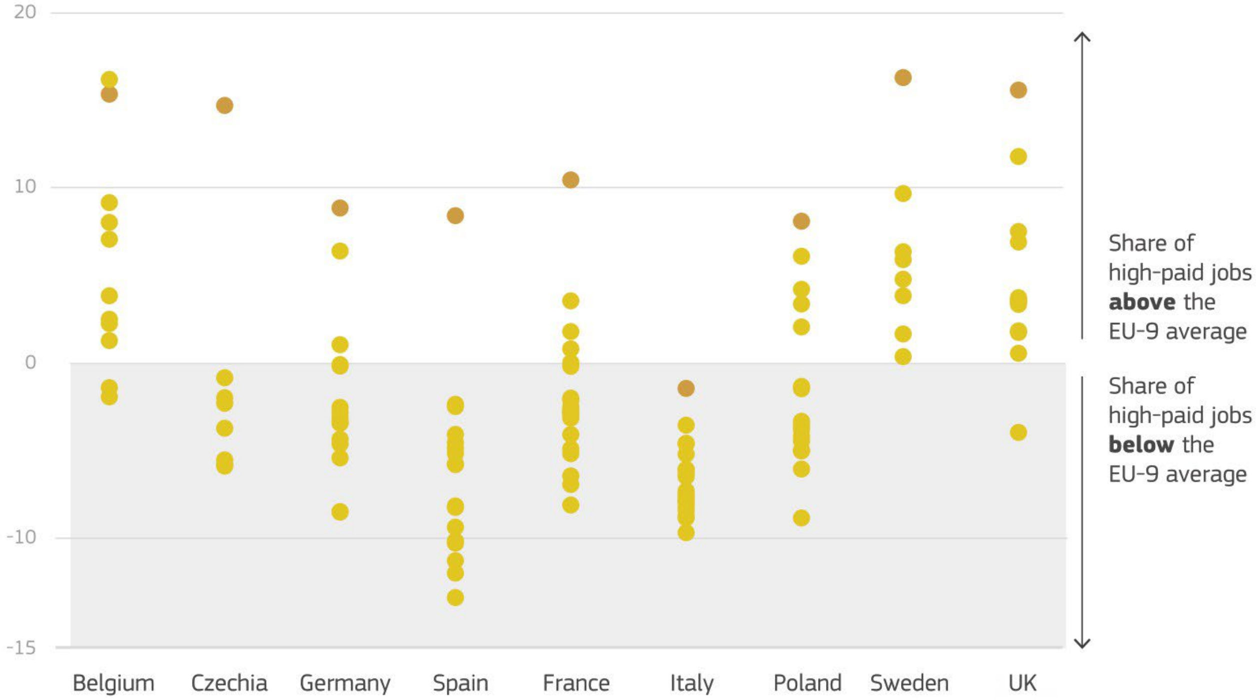


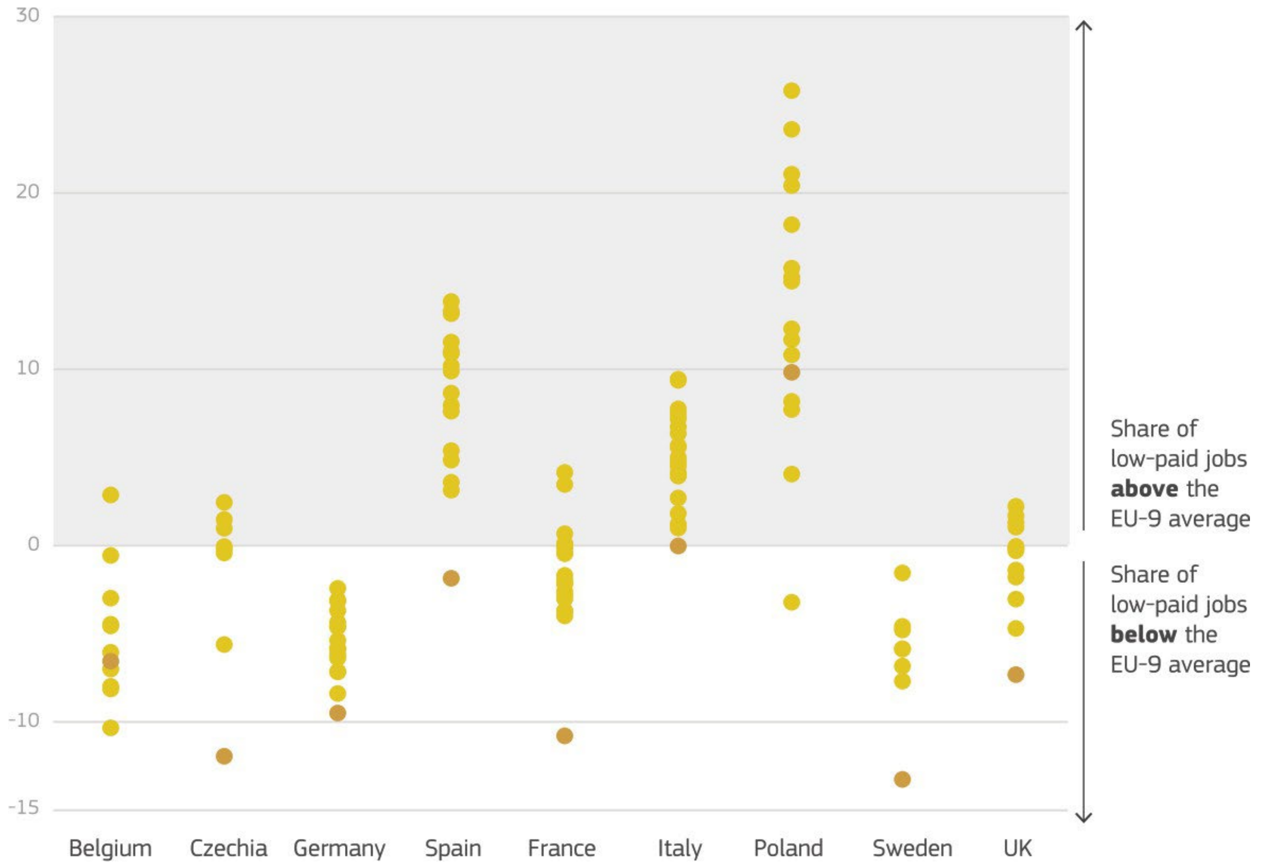
Note: covers employment in 21 Member States. Red line represents the even distribution of the quintiles

This holds not only at the aggregate level for a selection of 21 EU countries (see footnote 20), but also individually for many EU countries, according to Figure 20:

- Regions with very high shares of high-paid jobs tend to cluster within each country. In almost all of the nine countries analysed by Hurley et al. (2019), capital regions and their neighbouring areas have a significantly higher share of high-paid jobs than the rest. The strongest concentration of high-paid jobs in capital regions occurs in Czechia, France, Sweden, and the UK. This reflects a long-term shift in which capital regions and highly urbanised areas have disproportionately benefited from employment growth, particularly in the highly paid segment of the workforce: on average, the share of high-paid jobs in capital regions grew from 41.9% in 2002 to 44.7% in 2017.
- In some peripheral regions, particularly in southern Italy and Spain, as well as in certain Polish regions, the share of low-paid jobs exceeded 50% in 2017. Relatively high shares of low-paid jobs are also observed in some regions of France and the UK. In any case, the differences in the prevalence of low-paid jobs between capital regions and other regions are less pronounced. In the nine countries analysed, capital regions tend to have some of the lowest shares of low-paid jobs relative to the average. However, the share of low-paid jobs in capital regions does not differ dramatically from that in other regions within the same country, unlike the stark differences observed in high-paid jobs. In fact, in several countries, including Belgium, Italy, and Poland, capital regions have a larger share of low-paid jobs than some other regions within their country.

Figure 20. Difference in the share of high- and low-paid jobs across regions (2017)

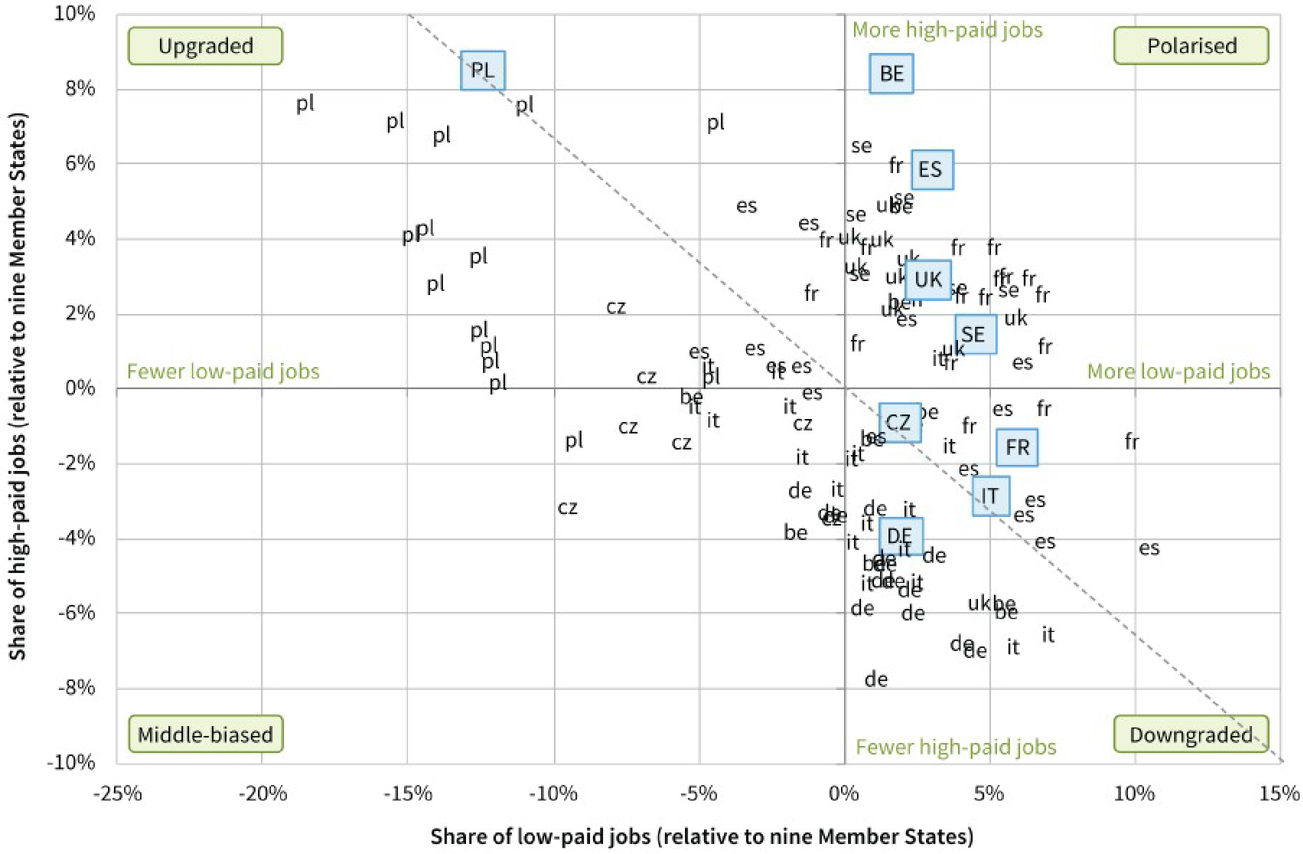




Source: González Vázquez et al (2019) and Hurley et al. (2019), based on EU-LFS data.
Note: difference in the share of high and low-paid jobs across regions in 2017 (pp deviation from EU-9 average)

This corroborates the idea that capital regions do not only attract high-skilled labour but also large numbers of workers who find employment in traditionally low-skilled services. As a result, an asymmetric form of job polarisation (skewed towards the best-paid jobs) tends to be found in these regions. This is explained, among other reasons, by the existence of consumption spillovers: since there are more qualified and high-income workers in these areas, there is also greater demand for services of all types, which are often provided through low-quality service jobs such as personal and care services or hospitality. As a result, labor markets in capital regions are most likely to show signs of job polarisation, as shown in Figure 21.

Figure 21. Regional occupational change compared to average, 9 countries (2002-2017)



Source: Hurley et al. (2019), based on EU-LFS and SES data.
Note: capital city regions denoted by boxed capital country codes, other regions by lowercase country codes.

The regressive and levelling impact of COVID-19

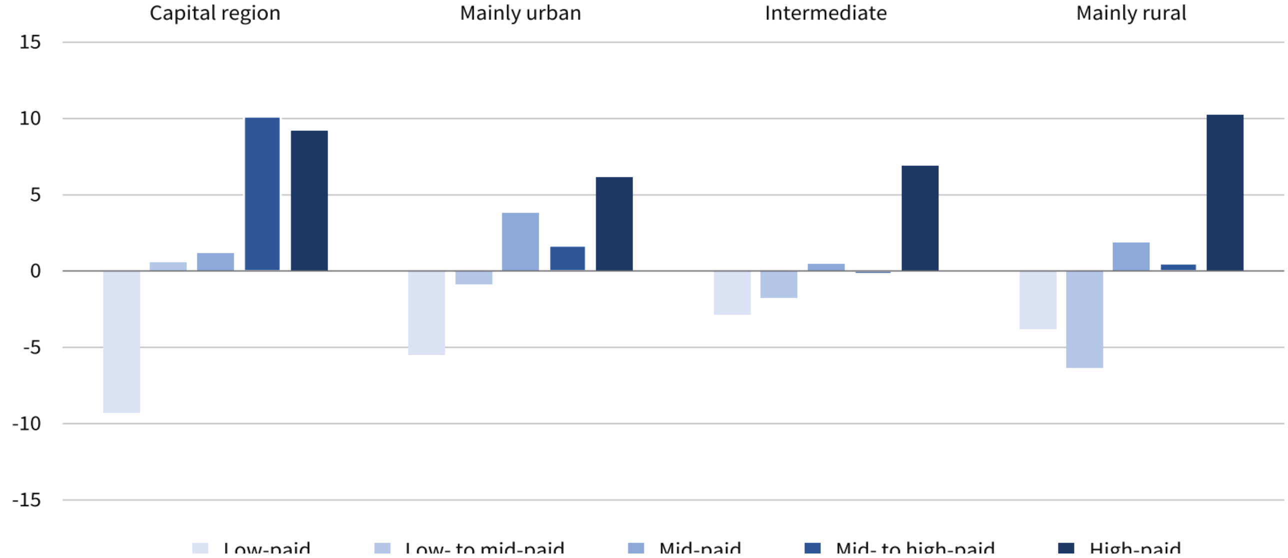
COVID-19 marked a clear break in employment trends. In most countries, the employment impact of the pandemic was asymmetric and regressive, having a net negative impact only for low-wage workers (Torrejón Pérez et al. 2023; 2025). This extends to the regional level: since COVID-19, and in clear contrast to the past, there has been no significant regional variation in patterns of occupational change. From 2019 to 2022, a significant degree of similarity emerged in the patterns of employment shifts by job-wage quintile across all region types, leading to occupational upgrading in all cases (see Figure 22). In every type of region, as in most countries, there were significant declines in low-paid jobs, varying patterns of slightly negative or positive shifts in mid- and mid-to-high-paid jobs, and notable increases in high-paid jobs. It is worth noting that this is not a long-term trend but rather a new form of employment restructuring in response to some of the new challenges created by the pandemic, mainly:

- From 2020 onwards, social distancing restrictions impacted mostly lower-paid contact-intensive services (Fana et al. 2020). A type of services that are often low-paid, and that tend to have a higher prevalence in capital and urban regions. That would explain why, although generalised, job losses in bottom quintiles have been most intense in these regions.

- The rapid expansion of telework (see chapter 4), as documented by Sostero et al. (2020) and Bisello et al. (2024), which served to protect employment especially in top-paying jobs. In relation to this phenomenon, the COVID-19 pandemic accelerated ongoing processes of digital transformation in many sectors, in part to facilitate increased remote working, and all regions (but especially capital regions, again) benefited from the associated hiring.

Although other factors contributed to recent trends in occupational change, the aforementioned have played a key role in explaining developments across all EU regions from 2019 to 2022, and help to clarify why all regions and countries have experienced similar patterns since COVID-19.

Figure 22. Employment shifts by job-wage quintile and region type (% change), EU (2019-2022)



Source: Bisello et al. (2024), based on EU-LFS and SES data. Note: covers employment in 21 Member States, after excluding Cyprus, Estonia, Latvia, Luxembourg, Malta and the Netherlands.

6.3 Female employment is more polarised, but has been upgrading

When analysing trends by gender, it is fundamental to distinguish between static and dynamic analyses. In a static snapshot of male and female employment structures, we tend to observe that female employment is more polarised, meaning it is more concentrated at the extremes of the wage distribution (low- and high-paid jobs, such as personal or care services on the one hand, and services related with health and education on the other). However, when focusing on changes over time, the main takeaway is that female employment growth has been more pronounced in top-paying jobs. In other words, although female employment structures tend to still be more polarised, it is also true that over time, women have contributed more to occupational upgrading than men. In this section, we attempt to unravel this puzzle.

Starting from a static analysis, as emphasised by Mariscal-de-Gante et al. (2023), data reveals that women have always been more prevalent in low-paid jobs. This was true a few decades ago, when employment rates for women were much lower than for men, and it remains true today, even though the gender employment rate gap has narrowed. Interestingly, where the gender gap in participation is larger, the gap in high-paid jobs is smaller (Mariscal-de-Gante et al. 2023). This suggests a filtering effect: in contexts and regions where female participation is low, the few women who do participate tend to come from higher social strata and thus hold relatively high-paid jobs. Conversely, where labour market participation is more gender-balanced, women from all social backgrounds occupy a wider range of employment niches. As a result, the increase in female participation has been accompanied by greater diversification in women's job roles, driven particularly by the expansion of low-paid jobs among women.

While women are overrepresented in low-paid jobs, men are more prevalent in high-paying jobs. The differences in the latter case are not as pronounced as in the former. As a result, female employment tends to be more biased than male employment towards both ends of the job-wage structure. That implies that female employment is more polarised.

However, although this observation has been consistent over the last few decades, it only illustrates on the composition of the employment structure at specific moments. A different and more relevant approach for this chapter involves analysing how female and male employment have contributed to shaping patterns of occupational change over time (Torrejón Pérez et al. 2023, 2024, 2025; Hurley et al. 2021). Although female employment is more polarised, women have experienced a significant degree of occupational upgrading in recent decades. Figure 23 reveals that, in recent decades, female employment growth has been more intense than male employment in top-paying jobs. Women, in each of the three periods, have benefited most from employment growth in well-paying jobs and their employment shifts have been more upgrading (skewed towards higher paying jobs) than men's.

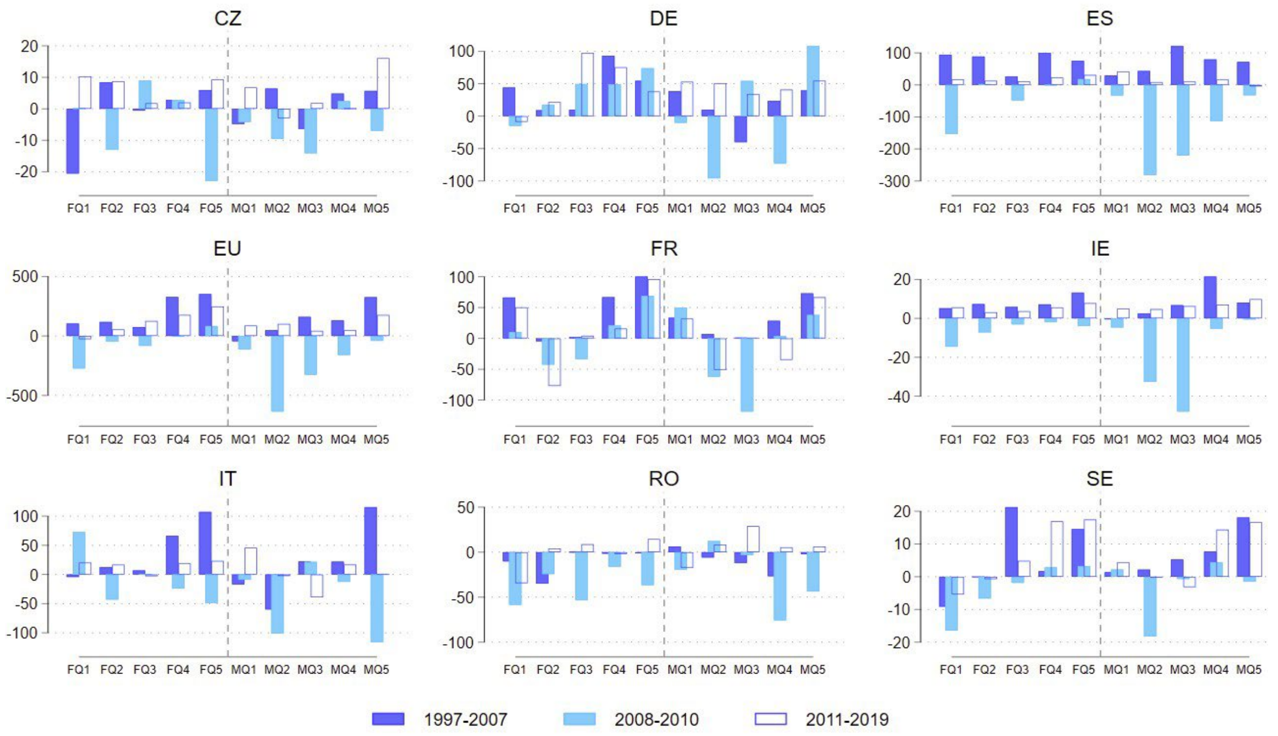
Since women have traditionally been overrepresented in low-paid jobs and underrepresented in top-paying jobs, this has also meant they have had greater potential for upward mobility within the job-wage structure. Given this scenario, and considering that educational upgrading has been particularly significant for women, we can better understand why a large share of female employment has occurred not only in low-paid, care-related, and personal service occupations, but also in public services such as health, education, and public administration, which often offer above-average wages. Employment growth in predominantly state-paid sectors has contributed to the upward shifts observed among women. As a result, many jobs in these sectors are now female-dominated. Consequently, in recent decades, the growth of female employment has been more intense than that of male employment in high-paid service jobs, with the feminisation of employment contributing this way to occupational upgrading.

As discussed in the previous sections, occupational upgrading is the most commonly observed pattern of occupational change globally, and it seems that the feminisation of employment has been strongly linked to this trend in some countries. This holds true for the EU8[20] as a whole across all subperiods and in the long term (see Figure 23) as well as in various EU and non-EU countries (Torrejón Pérez et al., 2023; 2025; Hurley et al., 2021). However, although this is the most common pattern, employment trends by gender are not uniform and vary significantly from one country and period to another (Torrejón Pérez et al. 2023; 2025; Hurley et al.,2021), which is why it is not advisable to extrapolate findings from the EU context to all regions and countries.

---

20 The Czech Republic, Germany, Spain, France, Ireland, Italy, Romania and Sweden.

Figure 23. Annual employment change by quintile and gender, EU8 (1997-2019)



Source: Torrejón Pérez et al. (2023), based on EU-LFS and SES data.
Note: Changes in thousands. 'F' stands for female and 'M' for male

Notably, in the few countries where job polarisation has been consistently observed over the last few decades (the US, South Korea, and France), female employment growth has tended to follow a more polarized pattern (Torrejón Pérez et al., 2023; 2025). It seems that, where the feminisation of employment is polarised, it tends to be associated with a general pattern of job polarisation overall; whereas feminization accompanied by upgrading tends to be associated with occupational upgrading in overall trends. As argued by Dwyer (2013), this may suggest that a particular type of polarized feminization of employment, particularly linked to the care economy in the US, helps explain the overall pattern of job polarisation that characterizes the US and other advanced economies. However, evidence from other countries shows that there is nothing intrinsically polarizing about the feminisation of employment and the growth of the care economy, as these same phenomena have contributed to occupational upgrading in most countries (Torrejón Pérez et al., 2023; 2025, Hurley et al. 2021).

6.4 Key findings and conclusions

Our research on occupational change shows that there is no single pattern of occupational change prevailing across countries, regions, and periods; instead, there is a wide variety. The business cycle exerts a clear influence on the shape of employment change patterns, as do various factors operating at the supranational level (such as technology and changes in trade), national level (institutional frameworks), and regional level (sectoral composition of the economy, demographics, etc.). Despite this wide heterogeneity, the most common transformation in the EU and globally in the first decades of the 21st century has been one of occupational upgrading: high-paid positions have grown the most in recent decades.

This trend is influenced by several factors, with deagrarianisation, tertiarisation, and the feminisation of employment (female employment is still more polarised, but in recent decades, female employment growth has contributed more to job upgrading, as it has been more concentrated in high-quality jobs) playing significant roles.

At the regional level, there has been convergence in employment structures within countries, with regional employment structures becoming more similar over time. However, generally in the EU, high-quality jobs are more prevalent in capital and innovative regions. These regions are also more likely to be polarised, as they concentrate both high-paid jobs (such as professional services) and low-paid service jobs (such as those related with care and hospitality).

Our findings are relevant because they challenge some ideas that have long dominated the debate, particularly the notion that job polarisation was a pervasive pattern of structural change in the digital age. According to new evidence, these ideas have now been proven inconsistent with the evidence in many countries. Instead, new findings offer a much more nuanced perspective, highlighting the heterogeneity of results across countries and regions and providing a more detailed and optimistic outlook on changes in employment structures in the long term.

These results highlight the importance of addressing other research questions that remain largely unanswered, such as: why has the pace and intensity of structural change slowed over the past few decades? How do patterns of structural change relate to productivity trends? Furthermore, the limitations of these studies underscore the need to develop analyses on labour market transitions. While the approach of comparing employment structures at two different points in time is intuitive and visually engaging, it does not provide insights into the specific trajectories that individual workers follow over time. Research on labour market transitions, especially if conducted with longitudinal data, would allow for better identification of those moving upward or downward along the employment structure, as well as those transitioning from employment to unemployment or inactivity, and vice versa. This would help to open the black box currently exist, and to refine current analyses and advance knowledge in the field. Finally, we now have access to new, detailed data on tasks at work for Europe (see Chapter 7), both at the occupational level (Bisello et al., 2021; Fernández-Macías and Bisello, 2021; Fana et al., 2023) and the individual level (the ad-hoc module on job skills of the EU-LFS 2022, released in 2024). These tools may allow for deeper analyses and a better characterization of employment change.

“Our research on occupational change shows that there is no single pattern of occupational change prevailing across countries, regions, and periods; instead, there is a wide variety.

Despite this wide heterogeneity, the most common transformation in the EU and globally in the first decades of the 21st century has been one of occupational upgrading.”

TASKS AND SKILLS

In recent decades, tasks have become a central lens through which labour markets are studied (Autor, 2013). From telework and offshoring to automation, robotisation and artificial intelligence (AI), researchers base their analysis of such technological and organisational changes on the task content of jobs or occupations. When we know which tasks people do at work, we can assess how exposed they are to change, now or in the near future. In turn, this assessment at the task level informs us about potential effects at the level of entire occupations, industries, regions or countries.

At the same time, the policy response to these labour market changes is firmly grounded in the concept of 'skills'. The European Skills Agenda puts forward actions to ensure that people have the right skills for jobs. It also aims to assist people in their lifelong learning pathways and unlock public and private investment in skills. This approach has gained much support as the European Year of Skills concluded in 2024 with calls for extending the effort into a 'decade of skills', and the European Commission is proposing a new initiative around the 'Unions of Skills' in 2025.

However, tasks are characteristics of jobs, while skills belong to people. Changes in one have been met with policy responses targeting the other. Linking the two in a conceptually sound and empirically supported way is thus imperative. The JRC has done extensive work to connect the concepts of tasks and skills. Taxonomies and dictionaries have been developed to bridge research and policy in diverse disciplines such as economics, sociology, psychology and education. This chapter presents the JRC's foundational frameworks and its applied research on tasks and skills. It concludes with gaps and potential future research avenues.

> "Tasks are characteristics of jobs, while skills belong to people."

7.1 Foundational frameworks for tasks and skills

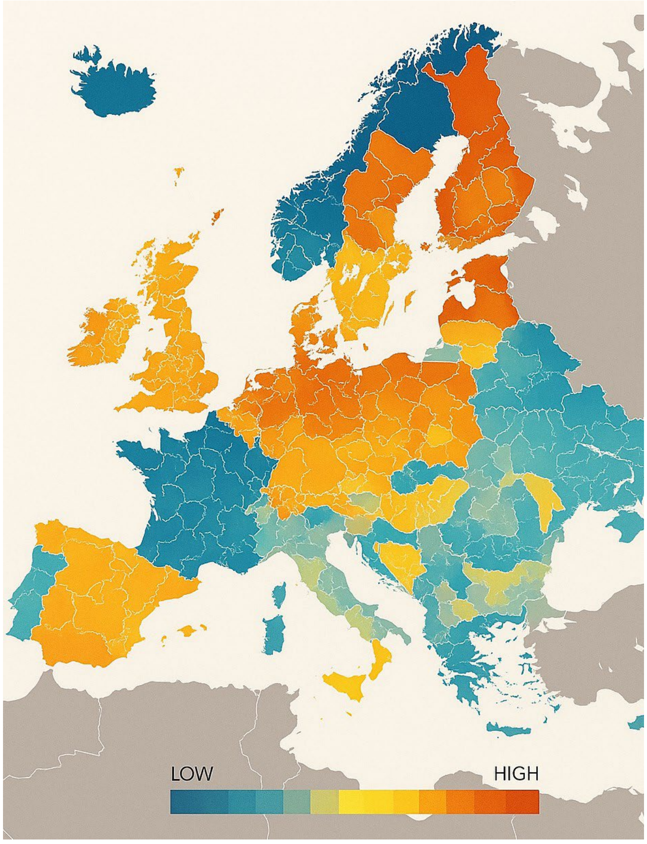
A comprehensive taxonomy of tasks

While the task-approach has become part of the canonical framework in labour economics and beyond, no generally accepted measurement of tasks has emerged yet. Most researchers use some version of the dimensions put forward by Autor et al. (2003), that differentiated between manual and cognitive work, and routine and non-routine tasks, but adapt their basic categorisation depending on data availability and the specific research question.

Not only does the lack of a standard framework make comparisons across studies difficult, but existing typologies also share the same conceptual weakness. Importantly, they take a strictly technical view on the task composition of work and ignore the social structures in which these tasks emerge, are assigned and are coordinated. The comprehensive taxonomy put forward by Fernández-Macías & Bisello (2022)[21] aims to overcome this weakness by separating the material content of work (what people do at

21 We have constructed a database of task indices (the JRC-Eurofound task database) at the occupational and sectoral level based on this taxonomy (Bisello et al., 2021). This database is based on data from the 2015 European Working Conditions Survey (EWCS), the OECD's Program for the International Assessment of Adult Competencies (PIAAC) Survey, and a European (Italian) version of the O*NET database of occupational contents (Indagine Campionaria delle Professioni, ICP 2012), and is publicly available to the research community and anyone interested in the following link: https://publications.jrc.ec.europa.eu/repository/handle/JRC124124


JOIN US


LOW
HIGH

work) from the organisational form of work (how people do what they do at work). While the content of work originates from the type of production of goods or services (the activity that transforms inputs into outputs), the methods and tools originate from the type of work organisation and technology used across the production tasks.

Within the content of work, the taxonomy classifies tasks based on the type of object upon which the task is performed – or the type of object that undergoes the transformative activity: physical tasks that operate on things, intellectual tasks that operate on ideas and social tasks that operate on people. The methods of work distinguish different methods for coordination across tasks. This coordination can happen trough the instalment of standardized routines, through human coordination within teams, or through autonomous decision-making by a single worker for his or her own tasks. The latter one can also be defined as the opposite of managerial control. Finally, the tools of work separate analogue from digital tools.

The taxonomy's distinction between production and coordination in organizations bridges several disciplines. It can be found for example in the production function and governance function of transaction cost economics (Williamson, 1981) the production structure and control structure of sociotechnical systems theory (de Sitter et al., 1997) and the principles of division of labour and integration of effort in organization design (Puranam, 2018). It is also connected with the labour process tradition in sociology of work (Braverman 1974; see also Bagnardi and Maccarrone 2023). Importantly, this distinction clarifies why workers within the same 'technical' occupation might experience different levels of routine, autonomy or teamwork. Indeed, while those workers would execute the same type of transformative tasks on things, ideas or people, they might be managed in a different way by their organisation depending on different factors such as the business strategy, the managerial culture, the variety of products or services offered and the predictability of the local environment in which they operate.

Table 4. A taxonomy of tasks according to the content of work, methods and tools

A. In terms of the content:	B. In terms of the methods and tools of work:
1. **Physical tasks:** aimed at the physical manipulation and transformation of material things: a. *Strength:* lifting people and heavy loads, exercising strength. b. *Dexterity:* precisely coordinated movements with hands or fingers. c. *Navigation:* moving objects or oneself in unstructured or changing spaces 2. **Intellectual tasks:** aimed at the manipulation and transformation of information and the active resolution of problems: a. *Information processing:* I. Visual and/or auditory processing of uncodified/unstructured information II. Processing of codified information i. Literacy: a. Business: read or write letters, memos, invoices,… b. Technical: read or write manuals, instructions, reports, forms,… c. Humanities: read or write articles or books. ii. Numeracy: a. Accounting: calculate prices, fractions, use calculators,… b. Analytic: prepare charts, use formulas or advanced maths b. *Problem solving:* I. Information gathering and evaluation. i. Information search and retrieval ii. Conceptualization, learning and abstraction II. Creativity and resolution i. Creativity ii. Planning 3. **Social tasks:** whose primary aim is the interaction with other people: a. *Serving/attending:* responding directly to demands from public or customers b. *Teaching/training/coaching:* impart knowledge or instruct others c. *Selling/influencing:* induce others to do or buy something, negotiate d. *Managing/coordinating:* coordinate or supervise the behaviour of colleagues e. *Caring:* provide for the welfare needs of others.	1. **Methods:** forms of work organisation used in performing the tasks: *a. Autonomy* I. Latitude: ability to decide working time, task order, methods and speed. II. Control (in reverse): direct control by boss or clients, monitoring of work. *b. Teamwork:* extent to which the worker has to collaborate and coordinate her actions with other workers *c. Routine* *I.* Repetitiveness: extent to which the worker has to repeat the same procedures *II.* Standardisation: extent to which work procedures and outputs are predefined and encoded in a formalised system III. Uncertainty (in reverse): extent to which the worker needs to respond to unforeseen situations 2. **Tools:** type of technology used at work: *a. Non-digital machinery (analog)* *b. Digitally-enabled machinery* I. Autonomous (robots) II. Non-autonomous 1. Computing devices a. Basic ICT (generic office applications) b. Advanced ICT (programming, admin) c. Specialised ICT *2.* Others

Source: Fernández-Macías & Bisello (2022)

A unified conceptual framework of tasks, skills and competencies

Skills can generally be defined as the ability to do a task well, so the concepts of tasks and skills are intricately linked. Thus, for any of the above-mentioned task categories, there are relevant skills associated. But conceptually linking skills to tasks is only the starting point for building a unified conceptual framework of tasks, skills and competencies.

Rodrigues et al. (2021) introduce a hierarchy of skills in which skills can be classified according to their complexity and transferability. Skill complexity increases as more lower-level skills are required for mastering a given skill. Skill transferability depends on the similarity between the considered task and other similar tasks: generic skills are transferable to many similar tasks while specific skills cannot be transferred beyond the specific task[22]. The similarity between tasks defines clusters of tasks that the authors refer to as task domains. Analogously, a skill domain is defined as the cluster of skills corresponding to a certain task domain. Such a skill domain can be characterised by the complexity of the individual skills that compose the domain as well as the consistency (or transferability) among the skills in the cluster.

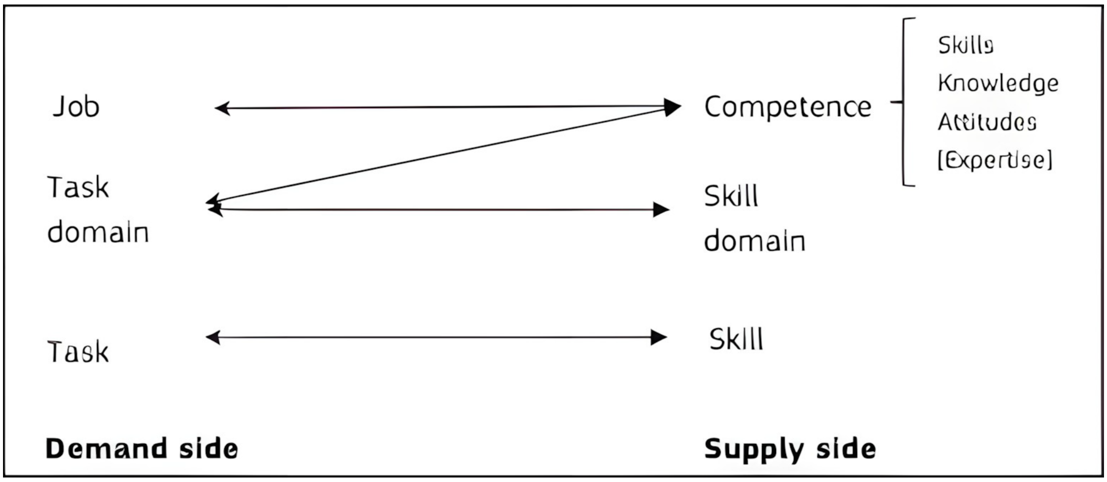
> "A unified framework of tasks, skills, and competencies shows how task bundling in jobs shapes skill demand. Competence is defined by the skills, knowledge, and attitudes required to perform well in a given task domain."

After defining skills and tasks, the authors define competence as the general ability to do well in a particular task domain. Such competence is made up of the skill domain associated with the tasks, a general knowledge of the domain and a particular set of attitudes. To the extent that jobs are made up of consistent task domains, competence thus also reflects the ability to perform well in the job. In this way, the unified conceptual framework illustrates how the bundling of tasks into jobs drives the demand for skills and competencies.

This unified framework (Figure 24) offers a foundation to define and monitor lifelong learning by introducing a dynamic competence production function across the lifetime. It posits that knowledge and attitudes are mostly acquired in childhood and early youth, while skills grow quickly through practice at work. Expertise is only acquired after starting the work period. The gains from expertise throughout the lifetime compensate the loss of knowledge and skills to keep competence high until retirement. These elements of the competence production function can be the building blocks of a lifelong learning monitoring framework (Rodrigues et al. 2021).

22 These two concepts (skill complexity and transferability) also show that foundational skills and transversal skills are distinct from each other. Foundational skills refer to the lower-level skills needed to acquire more complex skills, while transversal skills are those that can be transferred across tasks – regardless of their complexity. See also section 7.3 Soft skills.

Figure 24. A conceptual framework for tasks, skills and competencies



Source: Rodrigues et al. (2021)

A skill-task dictionary

After conceptually linking tasks and skills in a unifying framework, a big effort was undertaken by the JRC to operationalise these links in a Skills-Tasks Dictionary (Sostero & Fernández-Macías, 2021). Task indicators are retrieved from the JRC-Eurofound tasks database (Bisello et al., 2021) which is based on the abovementioned comprehensive taxonomy of tasks (see footnote 21). Skill keywords were taken from the Nova UK database of Burning Glass Technologies (BGT, now Lightcast), which covers 60 million individual online job advertisements (OJA) in the United Kingdom over the period 2012-2020. Jointly, these OJA mention over 13 000 distinct skills.

To link these skills from OJA to the taxonomy of tasks, Sostero and Fernández-Macías (2021) manually mapped 1,649 skills onto task categories covering 82.9 % of all skills mentioned. The authors find that, across occupations, the task profile implied in job advertisements is relatively consistent with the survey-based EU Task Database for intellectual and social tasks, and for tools of work. Physical tasks and the methods of work (except for standardization) however tend to be inconsistent between the two sources. This indicates that OJA data cannot be the only source for identifying the task content of jobs, at least for physical tasks and work methods. While the skills-task dictionary thus allows to assess the biases in OJA skills data, it also allows researchers to bring together analyses of labour demand and supply and it informs both researchers and policy makers to the use cases suitable for each type of data (see section 7.3).

7.2 Applications of the task framework to the vectors of change

The origin of the task-based approach in labour economics lies in the routine biased technological change (RBTC) theory put forward in Autor et al. (2003), although its main ideas can be traced back to labour process theory and the seminal work of Braverman (Braverman 1974). Autor et al. (2003) argued that technological change in the second half of the 20th century was biased towards replacing labour in routine tasks (both manual and cognitive). The automation of such routine tasks, which are more frequently present in middle-skill occupations, can contribute to job polarisation trends observed mostly in the US labour market (Goos et al., 2014), and to a lesser extent in some EU countries (Goos et al., 2009). Other authors[23] have contested these ideas, as we discussed in chapter 6.

Nonetheless, the concept of 'routine' has been a foundational concept in the task literature, both for assessing past changes in the employment structure as well as for anticipating potential future automation due to software (for routine cognitive tasks), robots (for routine manual tasks) or artificial intelligence (for non-routine cognitive tasks). Using our new taxonomy, the JRC has investigated the concept of routineness and its link to occupational change, gender and automation exposure.

(De)routinisation from automation, digitisation and platformisation

Fernández-Macías et al. (2022) use the taxonomy of tasks and the associated database to assess the RBTC theory in more detail. While earlier research classified entire occupations by their share of routine tasks, the JRC-Eurofound task database allows to explore the variation of routine tasks within occupations as well. Indeed, as mentioned above, considering routine as a fixed (or technical) characteristic of an occupation is misleading, given that routineness originates from the work organisation which can differ across organisations operating with the same occupations.

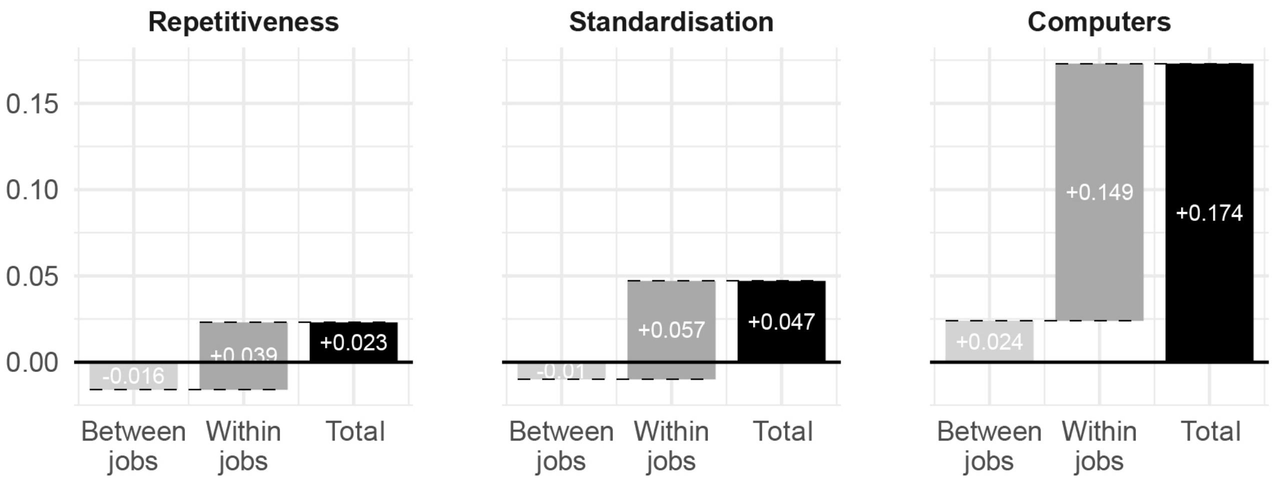
In both aspects of routineness – repetitiveness and standardisation – we find opposing trends across and within jobs: while employment in routine-classified occupations indeed decreased between 1995 and 2015, the reported routine-intensity within occupations increased significantly and substantially over the same period (see Figure 25). The authors dub these opposing trends deroutinisation of job structures and routinisation of work processes, highlighting that employment moves away from routine occupations while at the same time many

23 As discussed in chapter 6, many recent authors (including ourselves) have argued that neither was job polarisation as dominant as RBTC implies (Hunt & Nunn, 2022; Oesch & Piccitto, 2019; Torrejón Pérez et al., 2023; Torrejón Pérez et al. 2025) nor was it mostly driven by technical change but by other factors related to labour supply changes or institutions (Fernández-Macías & Hurley, 2017; Oesch & Rodríguez Menés, 2011).

occupations are becoming more routine. While the first observation confirms the RBTC theory, the second seems to contradict it at face value.

The authors also investigate computer use across and within occupations and they find that employment has moved somewhat towards computer-intensive occupations, but above all computer use has substantially increased within occupations across the board. Based on this insight, the authors put forward a hypothesis to explain these apparently contradicting trends in between- and within-job components of change in routineness. While computers can enable the automation of some routine cognitive tasks – thus reducing employment in these routine-intensive occupations – they also tend to facilitate standardization and bureaucratisation of procedures through digitised processes in non-routine occupations. While automation can thus reduce the amount of labour in routine tasks, digitisation facilitates the routinisation of previously non-routine tasks (see section 4.1 for a detailed discussion of digitisation, tasks and work organisation).

Figure 25. Aggregate and compositional change in task indices in EU-15 (1995–2015)



Source: Adapted from Fernández-Macías et al. (2022)

The authors note that this increasing routinisation through digitisation can then "pave the way for further rounds of automation, for types of work that were not automatable before". Indeed, historically automation has always been preceded by standardisation, and digitisation seems to facilitate this process. This dynamic systems perspective on routine-intensity is a useful contribution to the static typology of routine occupations in the literature that went before. As such, it provides insights that can guide research on future automation potential: business processes that are currently undergoing severe digitisation, such as processes in HR, marketing and finance, might be the next battleground of automation.

The above findings from the impact of computer use on routinisation cannot necessarily be generalised to all types of technologies adopted in workplaces. Case studies on the adoption of 3D-printing and Internet-of-Things technologies (discussed in chapter 4) found a resulting reduction in routineness (and increase in autonomy), especially for white-collar workers. However, case studies on the adoption of algorithmic management tools (discussed in chapter 5) found mixed evidence regarding the impact on work methods which seems to be mediated by the institutional and the regulatory frameworks in place.

Control, gender and wage

Fana et al. (2023) and Fana and Giangregorio (2021) further build out the conceptual underpinnings of the work methods section of the taxonomy of tasks. They link two sub-concepts of routine (repetitiveness and standardisation) to what labour process theory defines as technical and bureaucratic control. These are two forms of indirect control over workers exercised by the machines, tools and procedures that impose the goals, pace and methods of work (Edwards, 1982). Moreover, they split the concept of (direct) control into internal control (by supervisors) and external control (by clients), as detailed in Table 5.

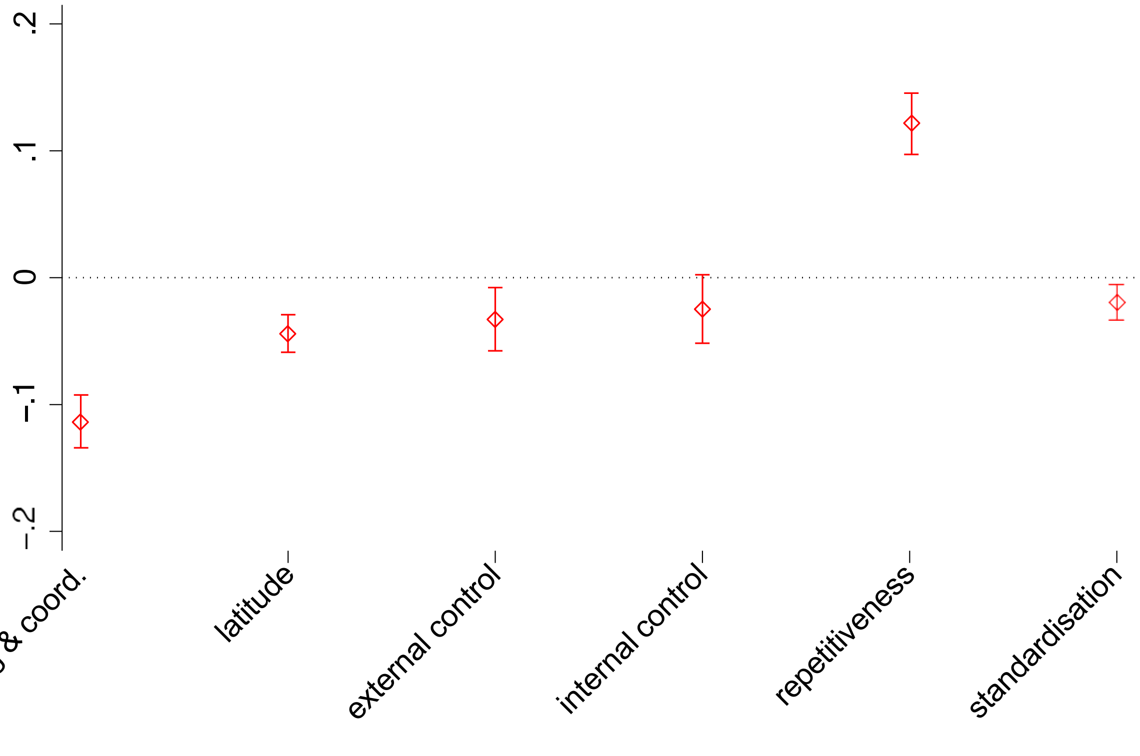
Table 5. Mapping the taxonomy of tasks to dimensions of control

Taxonomy of tasks		**Fana et al. (2023)**		**Definition**
Autonomy	Latitude	Latitude		The possibility of carrying out tasks independently.
	Control	Direct control	Internal control	The degree of direct control that workers experience from their bosses or supervisors within their organization.
			External control	The degree of control exerted on the workers by figures external to their workplace.
Routine	Repetitiveness	Indirect control	Technical control	Execution of the work involving the continuous repetition of gestures or operations.
	Standardization		Bureaucratic control	The extent to which the execution of work follows pre-codified standards and procedures.

Source: Based on Fernández-Macías & Bisello (2022), Fana et al. (2023) and Fana and Grangegorio (2021)

Equipped with these expanded concepts, the authors use the French Enquête Complémentaire Emploi: Conditions de travail (a representative survey of the French working population) to investigate how control is related to gender and wage in two separate studies. In both studies, patterns of direct and indirect control are analysed within jobs, defined as combinations of 2-digit NACE rev.2 sectors and 3-digit ISCO 08 occupations, which captures both the horizontal (sectoral) and vertical (occupational) division of labour. On gender gaps in workplace power, Fana et al. (2023) find that within the same job women tend to be subjected to more forms of control than men on average, even when taking into account other characteristics such as education, age and seniority (see Figure 26). These gender differences are often more marked in male-dominated jobs, although they do not necessarily disappear with an increasing share of women.

Figure 26. Gender differences in power and control



Source: Fana et al. (2023)

Note: Y-axis shows the estimated marginal effects with respect to the male baseline within jobs, controlled for individual and contractual characteristics.

Case studies in the automotive and apparel sectors in five countries (discussed in section 3.2) also illustrate that gender segregation at the task level remains pervasive, even as automation progresses (Fana et al., 2024). No evidence of defeminisation in apparel was found and automotive remains highly male-dominated. Automation technologies investigated in these case studies mainly targeted heavy repetitive tasks as the RBTC theory predicts. However, at the same time workers' autonomy deteriorated because of new indirect forms of controls and the high degree of standardisation induced by automation, similar to the argument made previously on digitisation and routinisation of work (Fernández-Macías et al., 2022).

In contrast, control and routine seem to have very little impact on wage differentials within the same job. Instead, contractual arrangements, working time and tenure are the principal determinants of individual wage. ICT use is positively associated with wages within the same job overall, but no clear pattern arises among different types of ICT (digital devices or digital applications) nor specific parts of the wage distribution. Their findings suggest that the RBTC theory needs a more nuanced understanding, as digital technologies keep evolving and building on top of each other.

The two studies on control, gender and wages taken together, seem to suggest that the gender pay gap within jobs would not be associated with gender differences in power and control. This could be further investigated in future research.

Automation exposure: robots and artificial intelligence

Nuancing the generalist RBTC theory requires diving into specific automation technologies such as robots – that can automate routine manual tasks – and artificial intelligence (AI) – which is hypothesized to expose non-routine cognitive tasks to automation.

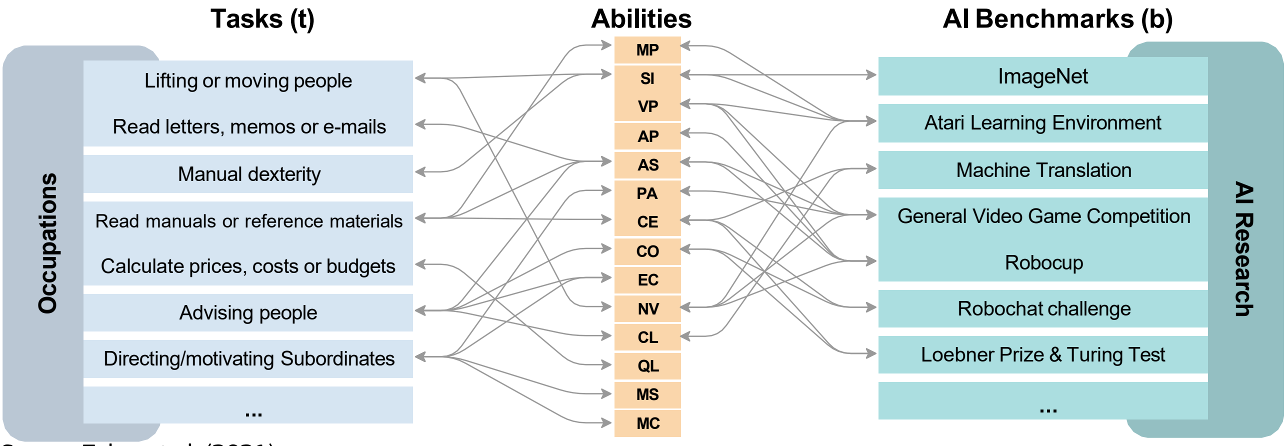
As discussed in chapter 3, Fernández-Macías et al. (2021) find that the functions and penetration of robots used in industry are limited to a few operations and specific country-sector pairs. They conclude that robots are not a disruptive force upheaving EU labour markets but rather a continuation of previous automation trends. In this sense, robots simply continue the historical process of industrial mechanisation and are more likely to replace earlier generations of robots than human workers. However, while the impact of robots on the EU labour markets has been small, the analysis of the determinants of robot adoption does support the general RBTC hypothesis. Sector-country combinations that have a high share of routine tasks see a significant and substantial increase in the adoption of industrial robots, confirming that these robots can perform repetitive manual tasks in scale-intensive industries.

Case studies of robotisation in service industries such as logistics, cleaning and health (discussed at large in section 3.3) offered a more nuanced view on the drivers of robot adoption. In healthcare, reducing routine tasks was found to be a driver for adopting televisit systems and some of the remote monitoring devices, but not for other remote technologies that were mainly aimed at saving time and lives. Likewise, cleaning robots and Automated Guided Vehicles were not adopted with the primary aim of reducing human input in routine tasks, but to improve safety and reduce errors and dead time. Labour displacement was not observed in any of these case studies.

AI is hypothesised to expose an even wider range of tasks and occupations to automation, moving the frontier of automation from routine to non-routine. Tolan et al. (2021) develop a new method to identify potential AI exposure of tasks, even those tasks for which AI applications have not yet been explicitly created, by mapping AI benchmarks to work tasks through an intermediate layer of cognitive abilities (see Figure 23)..

> "Robots mainly automate routine manual tasks and continue historical trends of mechanisation, with limited labour market disruption. In contrast, AI exposes non-routine cognitive tasks to automation, especially those involving ideas, with higher exposure in high-wage occupations."

Figure 27. Abilities as an intermediate layer between the mapping of tasks to AI benchmarks



Source: Tolan et al. (2021)

Contrary to the studies discussed in the previous pages that focus on the methods of work (routine and control), this study focusses on the content of work by mapping cognitive abilities to the work tasks that operate on things, ideas and people. Up until 2018, hardly any AI research was geared towards advancing AI's people-related abilities, which are widespread among many occupations. Most occupational AI exposure is instead driven by AI's ability to deal with ideas. If AI makes ideas-related tasks more productive, then workers that combine strong ideas abilities with strong people abilities (which are much less exposed) will be more in demand.

The AI exposure score displays a positive correlation with wages, indicating that high-income occupations are more exposed to AI progress. Indirectly, this points to the exposure of non-routine tasks and occupations, though future research might investigate this more explicitly.

7.3 Skills from online job advertisements

Strengths and weaknesses of online job advertisement data

Besides investigating the changing task composition of work, the JRC has also dived into the changing skill demand from employers. In recent years, online job advertisements (OJA) have become the main data source for measuring and tracking skill demand. In a Science for Policy Brief, Fernández-Macías & Sostero (2024) they can be converted into useful data for research. This data based on Online Job Ads (OJA discuss the strengths and weaknesses of this data for labour market intelligence and research (a more in-depth discussion can be found in Sostero and Fernández-Macías, 2021).

OJA data is a promising source for skills intelligence because of its richness, granularity and timeliness. Job adds contain rich information on job titles, geographic locations and contractual conditions, as well as task descriptions, qualifications and skills requirements. This richness in turn allows for more granular splits of skill demand by regions, occupations, sectors, time and type of skill. Due to the automated web scraping and processing of OJA, the data can be captured almost in real-time. Finally, new job titles and skills can be identified from this data as soon as they emerge in the market.

Given these benefits, OJA data has sparked an increased interest in labour market research, and skills demand in particular. Some of the main findings of this research shows an increased demand for both digital skills and soft skills, cutting across all occupations. OJA data also indicate that skill requirements within jobs are changing rapidly and that jobs tend to request a broader and more diverse skill set over time.

However, OJA data must be used with caution. Contrary to traditional survey data, OJA data is 'found' and not 'made', meaning that the data was originally created for other purposes than statistical. Fernández-Macías & Sostero collect the main biases in their policy brief, which can be grouped into representation bias – which vacancies are captured by the data – and measurement bias – what information is contained in and extracted from the captured vacancies.

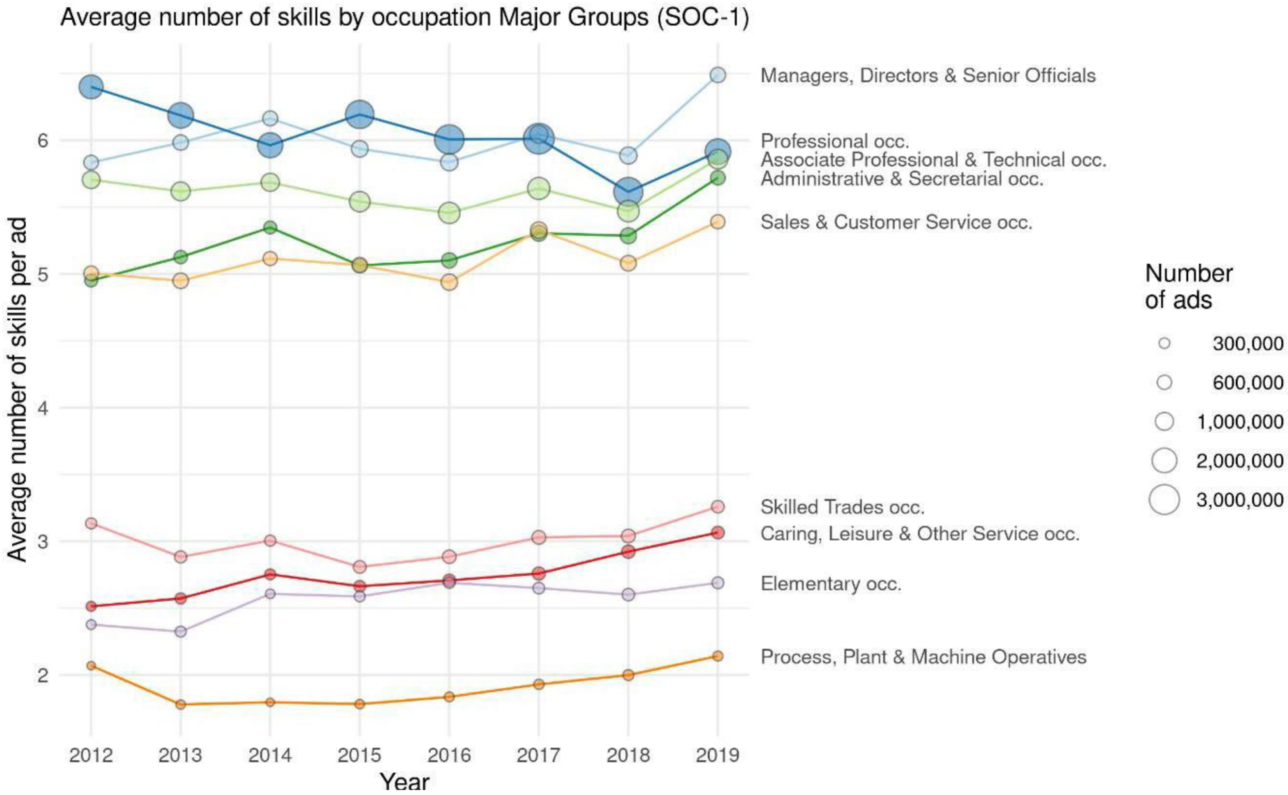
> OJA data provides rich, timely insights into employer skill demand. But it overrepresents high-skilled jobs and should complement, not replace, traditional labour market sources.

Regarding representation bias, the authors find that UK OJA data tends to overrepresent high-skilled and high-paid occupations such as managerial, professional and clerical positions (see Figure 28. Occupational trends in number of keywords mentioned per ad),

Manual and low-paid jobs on the other hand are underrepresented, compared to survey-based vacancy statistics (Sostero & Fernández-Macías, 2021). These findings are confirmed by the OECD, who also add that representativeness of OJA data is best in countries where public employment services have well-developed online tools for jobseekers and employers (Vermeulen & Amaros, 2024).

Measurement bias in OJA data arises from two sources: job vacancy texts are biased in the skills they list and algorithms that extract skills from the vacancy text are biased in how well skills are recognized. Skills that are more formalised and well-established can more easily be described by employers when drafting vacancy texts. Given that job advertisements are also talent attraction tools, socially desirable attributes of jobs – such as teamwork – are more likely to appear than unattractive ones – such as routineness or standardisation. Vacancies for more senior and complex jobs also tend to be more detailed (Goulart et al., 2022) Finally, the algorithms used for extracting skills have been created by high-skilled ICT professionals themselves, favouring again the coverage of digital skills and tools by their commercial names. Algorithms can also more easily identify and classify skills or terms in the OJA which are relatively standard and commonly used.

Figure 28. Occupational trends in number of keywords mentioned per ad



Source: Sostero & Fernández-Macías (2021)

Still, the authors conclude that OJA data are valuable for labour market intelligence, particular for detecting emerging skills and occupations. They should however complement, not replace, data from traditional surveys and administrative resources. OJA data also reflect current market needs rather than future skill requirements. Skill development through (vocational) education and training or work should be informed by strategic goals and long-term planning, where possible connecting both industrial policy goals with labour policy goals.

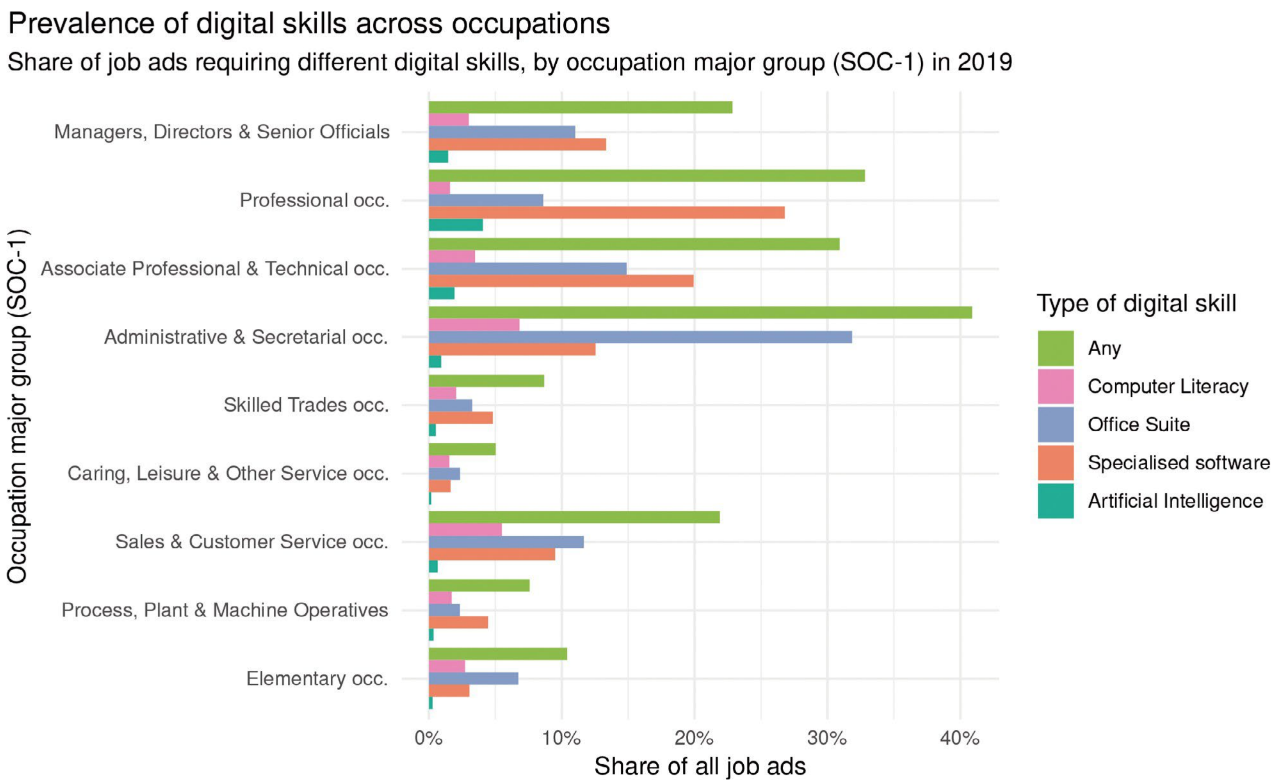
Digital skills

An increasingly digital workplace (see chapter 4) requires an increasingly digital-savvy workforce. Using OJA data, Sostero & Tolan (2022) track the demand for digital skills over the period 2012-2020 in the UK. A first finding is that basic digital skills needs have become so widespread across occupations, that they are often no longer explicitly mentioned in OJA (see Figure 29. Digital skills requested in Online Job Advertisements by occupation).). Instead, it is implicitly assumed that these skills are required, especially when more advanced digital skills are mentioned. As a result, OJA data underrepresent the need for basic digital skills, like computer literacy, compared to digital skills use indicators from representative surveys such as the European Skills and Jobs Survey.

The widespread need for basic digital skills also indicates that office software is now a core transversal skill in administrative and clerical domains. Similarly, digital skills are an important part of marketing & design skill clusters. Rodrigues et al. (2021) define transversal skills as generic skills that are transferable to many similar tasks. In this sense, the research by Sostero & Tolan (2022) indicates that basic digital skills should be counted among such transversal and transferable skills.

At the same time, basic digital skills can also be considered foundational skills, as they are "necessary for acquiring many important higher-level skills" – again in the definition by Rodrigues et al. (2021). That is why such skills are often omitted from OJA when more advanced digital skills are mentioned, as it is assumed that a person skilled in advanced digital applications also has basic digital skills.

Figure 29. Digital skills requested in Online Job Advertisements by occupation



Source: Sostero & Tolan (2022)

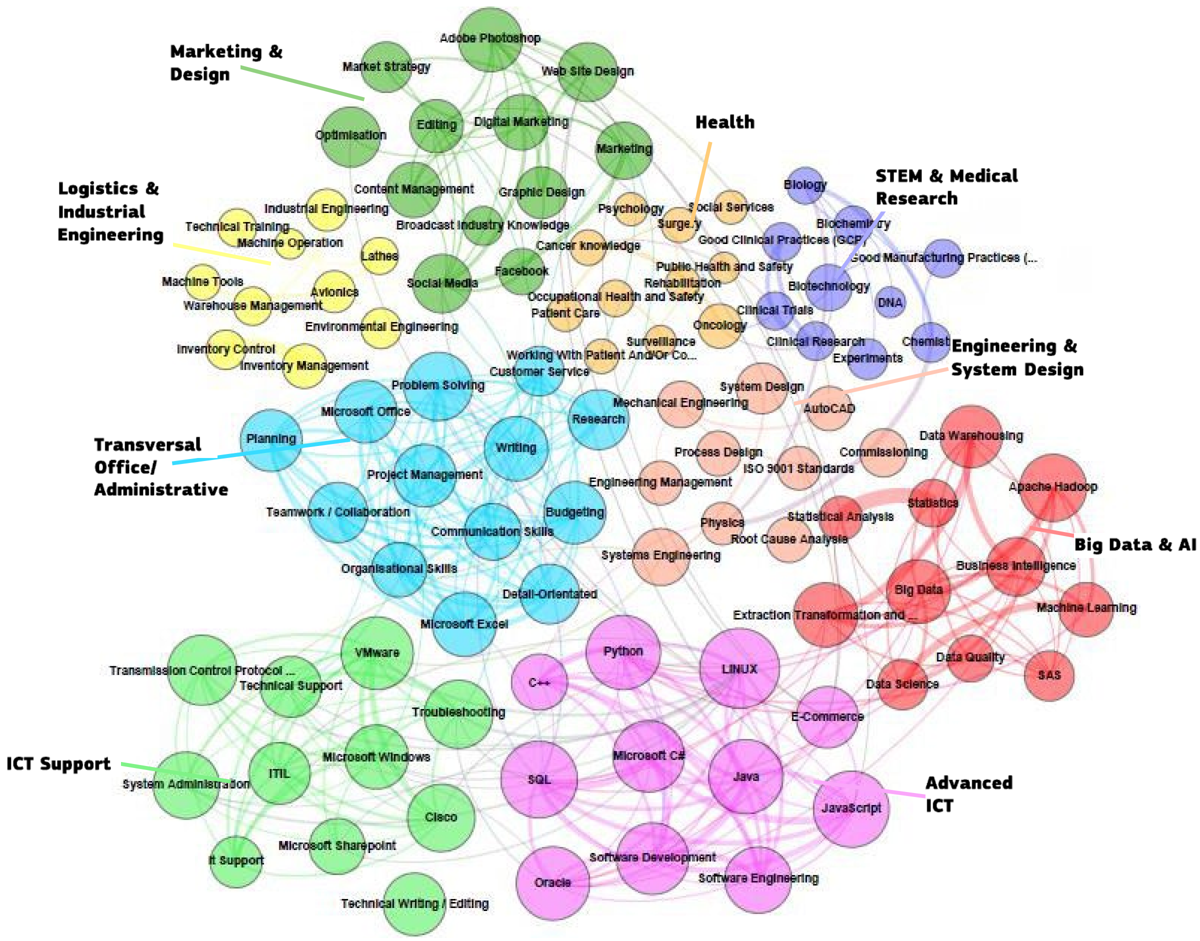
> Soft skills are widely used in job vacancies and HR processes but are poorly defined, often conflating attitudes, work methods, and actual skills.

OJA's comparative advantage lies exactly in detecting such emerging and advanced digital skills as well as the bundles in which they jointly appear. A study by Sostero & Tolan (2022) and by digitising existing jobs. As these changes unfold, new digital skills may be needed at the workplace. We track the trends in demand for digital skills across occupations, using data from over 60 million online job advertisements in the United Kingdom over 2012-2020, the longest-running dataset of this type in Europe. Although online job advertisements tend to understate the prevalence of basic digital skills (like computer literacy or office software finds three clusters of such advanced digital skills: (1) software development, (2) ICT technical support, and (3) big data and AI (see Figure 30. Skill clusters detected in Online Job Advertisements).

These skill bundles started out as distinct clusters but are gradually becoming more interconnected with other skill bundles over time, indicating a mainstreaming of these skills.

Skill sets for specialist profiles like data scientist are still changing quickly and have not yet consolidated. However, more established occupations present stable skill requirements and do not show evidence of rapid transformation. Finally, advanced digital skills pay a wage premium even when controlling for occupation and industry: 16 % for software development, 11 % for big data and AI and 6 % for ICT support.

Figure 30. Skill clusters detected in Online Job Advertisements



Source: Sostero & Tolan (2022)

Soft skills

The pervasiveness of soft skills in OJA data warrants its own discussion. While transversal and foundational skills can conceptually be clearly distinguished, there is much less agreement on the meaning of 'soft skills'. The former are defined in the JRC's unified conceptual framework of tasks, skills and competencies (Rodrigues et al., 2021) by their horizontal and vertical positions in the framework: transversal skills are horizontally transferable across different tasks, while foundational skills are the lower-lying basis for building more complex, higher-level skills.

The general interpretation of soft skills does not fully align with ether of these two concepts. Basic digital skills, for example, are both transversal and foundational skills according to the above definition but are rarely considered soft skills. Soft skills are positioned against 'hard' skills, i.e. technical skills for dealing with things or tools (digital and analogue). Leveraging this opposition, the taxonomy of tasks (Fernández-Macías & Bisello, 2022) offers several categories that could be considered task domains for soft skills: intellectual tasks including information processing and problem solving; social tasks originating from the interaction with people; and methods of work including autonomy and teamwork.

Indeed, several business organisations[24] consider among the skills of the future – besides digital skills – categories that conspicuously align with the above three categories, namely cognitive, interpersonal and self-management skills. Cognitive skills, including critical thinking, problem-solving and analysis, align with the taxonomy's intellectual tasks. Interpersonal skills, including collaboration, communication and emotional intelligence, map to both social tasks and teamwork methods. And self-management skills, that include self-regulation, resilience and adaptability, could be considered foundations for the good execution of latitude (autonomy).

There are two important problems with this broad interpretation of soft skills. First, the category of 'self-management' aligns much more with the concept of attitudes than with skills. While a skill is the ability to execute a particular task well, attitudes are personality traits that contribute to a more effective performance in a domain (Rodrigues et al., 2021) . Whereas skills are learned in a targeted and intentional way, attitudes are developed throughout the lifetime resulting from one's social surroundings. Assuming that self-regulation, resilience or adaptability can be learned in the same way as Excel is misleading. A person becomes resilient by overcoming manageable challenges and learning from failure in their day-to-day life (Wright & Masten, 2005). Resilience is thus a product of lifetime experiences, not of a one-off training course.

Second, collaboration and teamwork are work methods, which are characteristics of the work organisation or the governance process, not characteristics of people. Good communication skills can facilitate teamwork, but they cannot fix role ambiguity or unclear decision-making processes. More importantly, 'good people' shouldn't have to make up for 'bad systems'. Expecting the worker to 'be a good team player', ignores the important structural choices that employers make when dividing labour and integrating effort. Similarly, while self-regulation can help workers cope with different emotional tasks, these worker attitudes should not be used as excuses for bad work methods.
The rising demand for social skills might thus reflect the changing work organisation due to digitisation, as described in chapter 4 – rather than direct complementarities at the task level between digital tools and soft skills. As digital technologies standardize and proceduralise work, workers may need more soft skills to overcome the complexities of increased bureaucratisation.

24 See for example McKinsey & Company https://www.mckinsey.com/industries/public-sector/our-insights/defining-the-skills-citizens-will-need-in-the-future-world-of-work#/ and World Economic Forum https://www.weforum.org/agenda/2020/10/top-10-work-skills-of-tomorrow-how-long-it-takes-to-learn-them/

Table 6. Hard, sof t and transversal 'skills' mentioned in interviews

Hard Skills	**Soft 'Skills'**	**Transversal 'Skills'**
Having a degree (e.g. engineering, architect, designer) Having specific credentials Having knowledge of specific tools and/or software Having experience in similar positions	Having 'empathy' Being 'extroverted' Being 'organised' Being a 'team player'	'Being a good fit' for the firm Embodying the 'firm's values' 'Honesty' 'Good attitude' Being 'motivated' Being a 'happy person'

Source: Goulart et al. (2022)

Labelling either work methods (such as team player or autonomous) or attitudes (adaptable or resilient) as soft skills is problematic. Soft skills – understanding skills as the teachable ability to execute particular tasks well – would thus fit best with the taxonomy's intellectual and social tasks, but this needs further conceptual elaboration.

Qualitative research by the JRC confirms both the conceptual confusion and the pervasiveness of soft skills (Goulart et al., 2022) HR managers that were interviewed use the word to refer to a broad range of workers' attitudes (like commitment), work methods (like teamwork) or skills (like organisation), see Table 6. Respondents admit that these aspects are much harder to assess, but still included them in many job advertisements, which explains the pervasiveness of soft skills in OJA data. Goulart et al. (2022) call for future research to investigate the usage and measurement of soft skills. We reinforce this call and stress that a conceptual definition should beware of the two pitfalls discussed in this section.

7.4 Key findings and conclusions

Research by the JRC has tried to provide conceptual clarity and extensive data on the changing nature of tasks and skills in relation to digitisation and automation. While automation technologies generally target routine tasks with already limited labour input, digitisation of business processes is becoming widespread across occupations and industries. As digitisation both facilitates and necessitates standardisation and proceduralisation, and as such routinise the work, it paves the way for new rounds of data-driven automation. These findings put strong nuance on the RBTC's prediction of decreasing routine-intensity of work due to automation of routine tasks, as it highlights more dynamic relationships between routineness, digitisation and automation. Future research on automation risk could therefore include investigating business processes that are currently undergoing severe digitization, such as processes in HR, marketing and finance.

Digitisation is not only routinising work, it also creates a higher demand for digital skills. Basic digital skills can by now be considered both transversal (i.e. applicable across many different tasks and occupations) and foundational (i.e. necessary for acquiring higher-order complex skills). At the same time, online job advertisements suggest a pervasive demand for 'soft skills' as well. Soft skills are often included in popular lists of 'future skills'. However, much less is understood at the moment about what soft skills are and how they should be measured. Therefore, future research on skills should clarify the concept of 'soft skills' and its relationship to the concepts of transversal and foundational skills which have been defined by Rodrigues et al. (2021

Future research connecting tasks and skills can also expand on the optimal bundling of tasks into jobs, both from a skills use and a skills development perspective. Good job design should include consistent task domains (so that a reasonable set of skills is required), but also enough task variety so that new skills can be learned on the job. In this way, job design and the resulting on-the-job learning can be a pathway to skills development, besides more traditional training.

Beyond jobs, the optimal bundling of tasks into teams could also be investigated in future research, through the concept of task interdependence. Interdependent tasks require coordinated actions (Thompson, 1967) and such coordination can happen trough the instalment of standardized routines, through human coordination within teams, or through autonomous decision-making by a single worker for his or her own tasks. Therefore, the nature and the bundling of tasks in teams will determine whether coordination is achieved through routine, teamwork or autonomy (elements of work methods in the taxonomy of tasks).

The above two perspectives on job design and team design move the narrative away from a technologically deterministic future and instead put the future in the hands of human designers. The EU could play a leading role in helping business shape this future in a human-centric way. A future in which jobs stimulate skills use and skills development so that both citizens and businesses can flourish.

> Automation targets routine tasks, while digitisation increases routineness through standardisation. This dynamic interplay boosts the need for both digital and soft skills - and calls for job and team designs that foster skill use and development.

REFERENCES

■ Acemoglu, D., & Restrepo, P. (2020). Robots and jobs: Evidence from US labor markets. Journal of political economy, 128(6), 2188-2244.

■ Albertini, M., G. Ballarino and D. De Luca (2020). "Social Class, Work-Related Incomes, and Socio-Economic Polarisation in Europe, 2005–2014." European Sociological Review. 36 (4): 513-532.

■ Antón, J. I., D. Klenert, E. Fernández-Macías, M. C. Urzi Brancati and G. Alaveras (2022). "The labour market impact of robotisation in Europe." European Journal of Industrial Relations. 28 (3): 317–339.

■ Autor, D. (2013). The "task approach" to labor markets: An overview. Journal for Labour Market Research, 46(3), Article 3.

■ Autor, D., L. F. Katz and M. S. Kearney (2006). "The Polarisation of the U.S. Labor Market." American Economic Review. 96 (2): 189-194.

■ Autor, D., Levy, F., & Murnane, R. J. (2003). The Skill Content of Recent Technological Change: An Empirical Exploration. The Quarterly Journal of Economics, 118(4), 1279–1333.

■ Bagnardi, F., & Maccarrone, V. (2023). Labour Process Theory: taking stock and looking ahead. Sociologia del lavoro: 167, 3, 2023, 33-55.

■ Bailey, D. E. (2022). Emerging technologies at work: Policy ideas to address negative consequences for work, workers and society, in ILR Review, 75(3): 527-551.

■ Baiocco, S., Fernández-Macías, E., Rani, U., & Pesole, A. (2022). The algorithmic management of work and its implications in different contexts (No. 2022/02). JRC Working Papers Series on Labour, Education and Technology.

■ Baldwin, R. (2016). The great convergence: Information technology and the new globalization. Harvard University Press.

■ Ball, K. (2021). Electronic Monitoring and Surveillance in the Workplace. Literature review and Policy Recommendations. JRC125716, Luxembourg: Publication Office of the European Union.

■ Bell, Daniel (1973) The coming of Post-Industrial Society. New York: Basic Books.

■ Bisello, M., et al. (2019). How computerisation is transforming jobs: Evidence from Eurofound's European Working Conditions Survey (JRC Working Papers on Labour, Education and Technology 2019/02, JRC117167). European Commission.

■ Bisello, M., Fana, M., Fernández-Macías, E., & Pérez, S. T. (2021). A comprehensive European database of tasks indices for socio-economic research (JRC Technical Report JRC124124; JRC Working Papers Series on Labour, Education and Technology). European Commission.

■ Bisello, M., M. Sostero, C. Litardi, J. Hurley and E. Fernández-Macías (2024). "Regional employment change and the geography of telework in Europe." Luxembourg: Publications Office of the European Union.

■ Braverman, H. (1974). Labor and Monopoly Capital: The Degradation of Work in the Twentieth Century. New York, NYU Press.

■ Brian Arthur, W. (2009). The nature of technology: What it is and how it evolves. Simon and Schuster.

■ Castro-Trancón, N., M. Zuazua-Vega, A. Osca, E. Cifre and A. L. García-Izquierdo (2024). "Effects of teleworking on wellbeing from a gender perspective: a systematic review." Frontiers in Organizational Psychology, Vol. 2. https://doi.org/10.3389/forgp.2024.1360373

■ CEA (1996). "Job Creation and Employment Opportunities: The United States Labor Market, 1993-1996." Washington DC: Office of the Chief Economist.

■ Cirillo, V., Rinaldini, M., Virgillito, M.E., Divella, M., Manicardi, C., Massimo, F.S., Cetrulo, A., Costantini, E., Moro, A. and Staccioli, J., Case studies of automation in services, Publications Office of the European Union, Luxembourg, 2022, ISBN 978-92-76-58953-2, doi:10.2760/347087, JRC129691.

■ de Sitter, L. U., den Hertog, J. F., & Dankbaarl, B. (1997). From Complex Organizations with Simple Jobs to Simple Organizations with Complex Jobs. Human Relations, 50(5), 497–534.

■ Doellgast, V., Wagner, I., & O'Brady, S. (2023). Negotiating limits on algorithmic management in digitalised services: cases from Germany and Norway. Transfer: European Review of Labour and Research, 29(1), 105-120. https://doi.org/10.1177/10242589221143044

■ Dwyer, R. (2013). "The Care Economy? Gender, Economic Restructuring, and Job Polarisation in the U.S. Labor Market." American Sociological Review. 78 (3): 390-416.

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

■ Engels, F. (1993). The condition of the working class in England. Oxford: Oxford University Press,

■ European Commission (2017). "Attitudes towards the impact of digitisation and automation on daily life. Special Eurobarometer 460." Brussels: European Commission.

■ Fana, M., Torrejón Pérez, S. & Fernández-Macías, E. Employment impact of Covid-19 crisis: from short term effects to long terms prospects. J. Ind. Bus. Econ. **47**, 391–410 (2020). https://doi.org/10.1007/s40812-020-00168-5

■ Fana M., Bisello M., Torrejón Pérez S., Fernández-Macías E. (2023), What workers do and how. A European database of tasks indices, Sinappsi, XIII, n.2, pp.128-146.

■ Fana, M. and Villani, D. (2023): "Is it all the same? Types of innovation and their relationship with direct control, technical control and algorithmic management". European Journal of Industrial Relations. https://doi.org/10.1177/09596801231180399

■ Fana, M., & Giangregorio, L. (2021). Routine-biased technical change can fail: Evidence from France (JRC Technical Report JRC125902; JRC Working Papers Series on Labour, Education and Technology). European Commission.

■ Fana, M., Bárcia De Mattos, F., Esquivel, V., Anzolin, G., Kucera, D. and Tejani, S. (2024). The effects of automation in the apparel and automotive sectors and their gender dimensions, Publications Office of the European Union, Luxembourg, doi:10.2760/94475, JRC136639.

■ Fana, M., Massimo, S. F., & Moro, A. (2022). Autonomy and Control in Mass Remote Working during the COVID-19 Pandemic. A Cross-Occupational Comparison. Relations Industrielles/Industrial Relations, 77(3).

■ Fana, M., Milasi, S., Napierala, J., Fernandez Macias, E., & Gonzalez Vazquez, I. (2020). Telework, work organisation and job quality during the COVID-19 crisis: a qualitative study (JRC Working Papers on Labour, Education and Technology 2020/11, JRC122591). European Commission.

■ Fana, M., Villani, D., & Bisello, M. (2023). Gender gaps in power and control within jobs. Socio-Economic Review, 21(3), 1343–1367.

■ Fernandez Macias, E., Urzi Brancati, M.C., Wright, S. & Pesole, A. (2023). The platformisation of work (EUR 31469 EN, JRC133016). Publications Office of the European Union. https://doi.org/10.2760/801282

■ Fernández-Macías, E. (2012). "Job Polarisation in Europe? Changes in the Employment Structure and Job Quality, 1995-2007." Work and Occupations. 39 (2): 157-182.

■ Fernández-Macías, E. (2018). Automation, digitisation and platforms: Implications for work and employment. Publications Office of the European Union.

■ Fernández-Macías, E., & Bisello, M. (2020). A taxonomy of tasks for assessing the impact of new technologies on work (JRC120618). European Commission.

■ Fernández-Macías, E., & Bisello, M. (2022). A comprehensive taxonomy of tasks for assessing the impact of new technologies on work. Social Indicators Research, 159(2), 821-841.

■ Fernández-Macías, E., & Hurley, J. (2017). Routine-biased technical change and job polarisation in Europe. Socio-Economic Review, 15(3), 563–585.

■ Fernández-Macías, E., & Sostero, M. (2024). Skewed signals? Confronting biases in Online Job Ads data (Science for Policy Brief JRC136599; Labour, Education and Technology). European Commission.

■ Fernández-Macías, E., Bisello, M., Peruffo, E., & Rinaldi, R. (2023). Routinization of work processes, de-routinization of job structures. Socio-Economic Review, 21(3), 1773–1794.

■ Fernández-Macías, E., D. Klenert and J.-I. Antón (2021). "Not so disruptive yet? Characteristics, distribution and determinants of robots in Europe." Structural Change and Economic Dynamics. 58 76-89.

■ Fernández-Macías, E., J. Hurley and J. M. Arranz-Muñoz (2017). "Occupational change and wage inequality: European Jobs Monitor 2017." Luxembourg: Publications Office of the European Union.

■ Freeman, C. and Louçã, F. (2001), As time goes by: From the industrial revolutions to the information revolution, Oxford University Press, UK.

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

■ Gonzalez Vazquez, I., Curtarelli, M., Anyfantis, I., Brun, E., & Starren, A. (2024). Digitalisation and workers wellbeing: The impact of digital technologies on work-related psychosocial risks (JRC138992). European Commission.

■ Gonzalez Vazquez, I., Milasi, S., Carretero Gomez, S., Napierala, J., Robledo Bottcher, N., Jonkers, K., Goenaga, X. (eds.) The changing nature of work and skills in the digital age, EUR 29823 EN, Publications Office of the European Union, Luxembourg, 2019, ISBN 978-92-76-09206-3, doi:10.2760/679150, JRC 117505.

■ Goos, M. and A. Manning (2007). "Lousy and Lovely Jobs: The Rising Polarisation of Work in Britain." Review of Economics and Statistics. 89 (1): 118-133.

■ Goos, M., A. Manning and A. Salomons (2009). "Job Polarisation in Europe." American Economic Review. 99 (2): 58-63.

■ Goos, M., A. Manning and A. Salomons (2010). "Explaining Job Polarisation in Europe: The Roles of Technology, Globalization and Institutions." CEP Discussion Paper. (1026): 1-89.

■ Goos, M., A. Manning and A. Salomons (2014). "Explaining Job Polarisation: Routine-Biased Technological Change and Offshoring." American Economic Review. 104 (8): 2509-2526.

■ Goulart, K. S., Rodríguez-Menés, J., & Armayones, J. M. C. (2022). Job descriptions, from conception to recruitment A qualitative review of hiring processes (JRC Technical Report JRC131040; JRC Working Papers Series on Labour, Education and Technology). European Commission.

■ Graetz G. and Michaels G. (2018). Robots at work. The Review of Economics and Statistics 100(5):753–768. doi: 10.1162/rest_a_00754.

■ Grande, R., Vallejo-Peña, A., & Brancati, C. U. (2021). The impact of IoT and 3D printing on job quality and work organisation: A snapshot from Spain (JRC Technical Report JRC125612; JRC Working Papers Series on Labour, Education and Technology). European Commission.

■ Guarascio, D., Piccirillo, A., & Reljic, J. (2024). Will robot replace workers? Assessing the impact of robots on employment and wages with meta-analysis (No. 2024/03). LEM Working Paper Series.

■ Hunt, J., & Nunn, R. (2022). Has U.S. employment really polarized? A critical reappraisal. Labour Economics, 75, 102117.

■ Hurley, J., and Fernández-Macías, E. (2009). "More and better jobs: Patterns of employment expansion in Europe." Luxembourg: Publications Office of the European Union.

■ Hurley, J., E. Fernández-Macías, M. Bisello, C. Vacas and M. Fana (2019). "European Jobs Monitor 2019: Shifts in the employment structure at regional level." Luxembourg: Eurofound and European Commission Joint Research Centre.

■ Hurley, J., S. Grubanov-Boskovic, M. Bisello, C. VacasSoriano, M. Fana and E. Fernández-Macías (2021). "European Jobs Monitor 2021: Gender gaps and the employment structure." Luxembourg: Publications Office of the European Union.

■ International Labour Organisation (2021). World Employment and Social Outlook 2021: The role of digital labour platforms in transforming the world of work. International Labour Office – Geneva: ILO, 2021.

■ Jungmittag, A. (2020). Robotisation of the manufacturing industries in the EU: convergence or divergence? The Journal of Technology Transfer.

■ Jungmittag, A. and A. Pesole (2019). The impact of robots on labour productivity: A panel data approach covering 9 industries and ■

■ 12 countries. JRC Working Papers Series on Labour, Education and Technology.

■ Kellogg KC, Valentine M and Christin A (2020) Algorithms at Work: The New Contested Terrain of Control. Academy of Management Annals 14(1): 366–410.

■ Keynes, J. M. (1930). Economic possibilities for our grandchildren. In Essays in persuasion (pp. 321-332). London: Palgrave Macmillan UK.

■ Klenert, D., E. Fernández-Macías and J.-I. Antón (2022). "Do robots really destroy jobs? Evidence from Europe." Economic and Industrial Democracy. 00 (0): 1-37.

■ Lee, M.K., Kusbit, D., Metsky, E., and Dabbish, L. (2015): "Working with machines: the impact of algorithmic and data-driven management on human workers", in Proceedings of the 33rd annual ACM

■ Maarek, P. and E. Moiteaux (2021). "Polarisation, employment and the minimum wage: Evidence from European local labor markets." Labour Economics. 73 102076.

■ Mariscal-De-Gante, A., A. Palencia Esteban, S. Grubanov-Boskovic and E. Fernandez-Macías (2023). "Feminization, ageing and occupational change." JRC Working Papers Series on Labour, education and Technology. 2023/04, JRC132328.

■ Mateescu, A., and Nguyen, A. (2019): "Algorithmic management in the workplace", Data & Society,

■ Milasi, S., González-Vázquez, I., & Fernández-Macías, E. (2021). Telework before the COVID-19 pandemic: Trends and drivers of differences across the EU. OECD Productivity Working Papers, 21.

■ Minnesota Population Center. (2019). Integrated Public Use Microdata Series, International: Version 7.2 [dataset]. Minneapolis, MN: IPUMS, 2019. https://doi.org/10.18128/D020.V7.2

■ Muñoz de Bustillo Llorente, R. (2024). A Critical Review of the Digital and Green Twin Transitions. Implications, synergies and trade-offs. JRC Working Papers on Labour, Education and Technology 2024-07, Joint Research Centre.

■ Muñoz de Bustillo, R., Fernández-Macías, E., Antón, J. I., & Esteve, F. (2011). Measuring More than Money: The Social Economics of Job Quality. In Measuring More than Money. Edward Elgar Publishing.

■ Oesch, D. (2015). Welfare regimes and change in the employment structure: Britain, Denmark and Germany since 1990. Journal of European Social Policy. 25 (1): 94-110.

■ Oesch, D., & Piccitto, G. (2019). The Polarisation Myth: Occupational Upgrading in Germany, Spain, Sweden, and the UK, 1992–2015. Work and Occupations, 46(4), 441–469.

■ Oesch, D., & Rodríguez Menés, J. (2011). Upgrading or polarisation? Occupational change in Britain, Germany, Spain and Switzerland, 1990–2008. Socio-Economic Review, 9(3), 503–531.

■ Parent-Rocheleau, X. and Parker, S. K. (2021). Algorithms as work designers: how algorithmic management influences the design of jobs, Human resource management review, p. 100838. DOI: 10.1016/j.hrmr.2021.100838.

■ Pérez, C. (2003), Technological revolutions and financial capital: The dynamics of bubbles and golden ages, Edward Elgar Publishing, Cheltenham, UK.

■ Peruffo, E. (2017), A literature review on the implications of digitisation for work and employment, Eurofound, Dublin.

■ Peruffo, E. and Schmidlechner, L. (2017), A literature review on the implications of automation for work andemployment, Eurofound, Dublin.

■ Pesole, A., Urzì Brancati, M.C., Fernandez Macias, E., Biagi, F. and Gonzalez Vazquez, I. 2018. Platform Workers in Europe Evidence from the COLLEEM Survey, EUR 29275 EN, Publications Office of the European Union, Luxembourg, 2018, ISBN 978-92-79-87996-8, doi:10.2760/742789, JRC112157.

■ Puranam, P. (2018). The microstructure of organizations. In Oxford scholarship online (First edition). OUP Oxford.

■ Rani, U., Pesole, A., & Gonzalez, V. I. (2024). Algorithmic Management practices in regular workplaces: Case studies in logistics and healthcare (JRC136063). Publications Office of the European Union.

■ Rifkin, J. (1995). The end of work. Putnam.

■ Riso, S. (2021). Digitisation in the workplace. Publications Office of the European Union.

■ Rodrigues, M., Fernández-Macías, E., & Sostero, M. (2021). A unified conceptual framework of tasks, skills and competences (JRC Technical Report JRC121897; JRC Working Papers Series on Labour, Education and Technology). European Commission.

■ Rodrik, D. (2018). New technologies, global value chains, and developing economies (No. w25164). National Bureau of Economic Research.

■ Roser, M. (2020) - "Why did renewables become so cheap so fast?" Published online at OurWorldinData.org. Retrieved from: https://ourworldindata.org/cheap-renewables-growth [Online Resource]

■ Schaupp, S. 2022. COVID-19, economic crises and digitalisation: How algorithmic management became an alternative to automation. New Technology Work and Employment. 2023;38:311–329

■ Schmidlechner, L. and Peruffo, E. (2017), A literature review on the implications of platforms for work and employment, Eurofound , Dublin.

■ Schmidt, O., Hawkes, A., Gambhir, A. et al. The future cost of electrical energy storage based on experience rates. Nat Energy **2**, 17110 (2017).

■ Smith, A. (1776). An inquiry into the nature and causes of the wealth of nations: Volume One. London: printed for W. Strahan; and T. Cadell, 1776.

■ Solow, R. (1987). "We'd better watch out", New York Times Book Review, July 12, 1987, page 36

■ Solow, R. M. (1957). Technical change and the aggregate production function. The review of Economics and Statistics, 39(3), 312-320.

■ Sostero, M., & Fernández-Macías, E. (2021). The Professional Lens: What Online Job Advertisements Can Say About Occupational Task Profiles (JRC Technical Report JRC125917; JRC Working Papers Series on Labour, Education and Technology). European Commission.

■ Sostero, M., & Tolan, S. (2022). Digital skills for all? From computer literacy to AI skills in online job advertisements (JRC Technical Report JRC130291; JRC Working Papers Series on Labour, Education and Technology). European Commission.

■ Sostero, M., Automation and Robots in Services: Review of Data and Taxonomy, European Commission, 2020, JRC121893.

■ Sostero, M., Milasi, S., Hurley, J., Fernández-Macías, E., & Bisello, M. (2020). Teleworkability and the COVID-19 crisis: a new digital divide? (JRC Working Papers on Labour, Education and Technology 2020/05, JRC121193). European Commission.

■ Sostero, M., Milasi, S., Hurley, J., Fernandez-Macias, E., & Bisello, M. (2023). Teleworkability and the COVID-19 crisis: potential and actual prevalence of remote work across Europe. IZA Journal of Labour Policy.

■ Sturgeon, T. J. (2002). Modular production networks: a new American model of industrial organization? Industrial and Corporate Change, 11(3), 451–496.

■ Thompson, J. D. (1967). Organizations in action: Social science bases of administrative theory. McGraw-Hill.

■ Tolan, S., Pesole, A., Martínez-Plumed, F., Fernández-Macías, E., Hernández-Orallo, J., & Gómez, E. (2021). Measuring the occupational impact of AI: tasks, cognitive abilities and AI benchmarks. Journal of Artificial Intelligence Research, 71, 191-236.

■ Torrejon Perez, S., Fernandez Macias, E. and Hurley, J., (2024). Global Shifts in the Employment Structure, Publications Office of the European Union, Luxembourg, doi:10.2760/969088, JRC136358

■ Torrejón Pérez, S., Fernández-Macías, E. and Hurley, J. (2025). Global Trends in Job Polarisation and Upgrading – A Comparison of Developed and Developing Economies. Palgrave Macmillan.

■ Torrejón Pérez, S., Hurley, J., Fernández-Macías, E., & Staffa, E. (2023). Employment shifts in Europe from 1997 to 2021: From job upgrading to polarisation (Working Paper 2023/05). JRC Working Papers Series on Labour, Education and Technology.

■ Torrejón Pérez, S., Fernández-Macías, E., González Vázquez, I. and Marqués Perales, I., The Working Times They Are A-Changing: Trends in Six EU countries (1992-2022), European Commission, 2024, JRC139815.

■ Urzì Brancati, M. C., & Curtarelli, M. (2021). Digital tools for worker management and psychosocial risks in the workplace: evidence from the ESENER survey (JRC125714). European Commission.

■ Urzì Brancati, M. C., A. Pesole and E. Fernández-Macías (2020). "New evidence on platform workers in Europe. Results from the second COLLEEM survey." Luxembourg: Publications Office of the European Union._

■ Urzì Brancati, M. C., Curtarelli, M., & Riso, S. (2022). How digital technology is reshaping the art of management (JRC130808). European Commission.

■ Vera-Toscano, E., M. Fana and E. Fernández-Macías (2022). "Regional heterogeneity in occupational change: using Census data to investigate employment polarisation and upgrading at NUTS-3 level." Labour, Education and Technology Working Paper Series. Seville: European Commission.

■ Vermeulen, W., & Amaros, F. G. (2024). How well do online job postings match national sources in European countries?: Benchmarking Lightcast data against statistical and labour agency sources across regions, sectors and occupation. OECD.

■ Villalobos, P., Sevilla, J., Heim, L., Besiroglu, T., Hobbhahn, M., & Ho, A. (2022). Will we run out of data? an analysis of the limits of scaling datasets in machine learning. arXiv preprint arXiv:2211.04325.

■ Weber, M. (2015, originally 1922): "Bureaucracy", in Waters, T. and Waters D. (eds.), Weber's Rationalism and Modern Society: New Translations on Politics, Bureaucracy, and Social Stratification, Palgrave MacMillan.

■ Weil, D. (2014). The fissured workplace: Why work became so bad for so many and what can be done to improve it. Harvard University Press.

■ Williamson, O. E. (1981). The Economics of Organization: The Transaction Cost Approach. American Journal of Sociology, 87(3), 548–577.

■ Wood, A. J., 'Algorithmic management consequences for work organisation and working conditions', JRC Working Papers Series on Labour, Education and Technology No 7, Seville, European Commission, 2021.

■ Wright, E. O. and R. Dwyer (2003). "The patterns of job expansions in the USA: a comparison of the 1960s and 1990s." Socio-Economic Review. 1 (3): 289-325.

■ Wright, M. O., & Masten, A. S. (2005). Resilience Processes in Development. In S. Goldstein & R. B. Brooks (Eds.), Handbook of Resilience in Children (pp. 17–37). Springer US.

■ Zuboff S. (2019). The age of surveillance capitalism: The fight for our human future at the new frontier of power. New York: Public Affairs.

LIST OF TABLES, FIGURES AND BOXES

LIST OF TABLES

LIST OF FIGURES

LIST OF BOXES

Getting in touch with the EU

In person

All over the European Union there are hundreds of Europe Direct centres. You can find the address of the centre nearest you online (european-union.europa.eu/contact-eu/meet-us_en).

On the phone or in writing

Europe Direct is a service that answers your questions about the European Union. You can contact this service:

— by freephone: 00 800 6 7 8 9 10 11 (certain operators may charge for these calls),

— at the following standard number: +32 22999696,

— via the following form: european-union.europa.eu/contact-eu/write-us_en.

Finding information about the EU

Online

Information about the European Union in all the official languages of the EU is available on the Europa website (european-union.europa.eu).

EU publications

You can view or order EU publications at op.europa.eu/en/publications. Multiple copies of free publications can be obtained by contacting Europe Direct or your local documentation centre (european-union.europa.eu/contact-eu/meet-us_en).

EU law and related documents

For access to legal information from the EU, including all EU law since 1951 in all the official language versions, go to EUR-Lex (eur-lex.europa.eu).

EU open data

The portal data.europa.eu provides access to open datasets from the EU institutions, bodies and agencies. These can be downloaded and reused for free, for both commercial and non-commercial purposes. The portal also provides access to a wealth of datasets from European countries.

Science for policy

The Joint Research Centre (JRC) provides independent, evidence-based knowledge and science, supporting EU policies to positively impact society

EU Science Hub
Joint-research-centre.ec.europa.eu

Publications Office
of the European Union