

The effects of automation in the apparel and automotive sectors and their gender dimensions



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Abstract

This report is the final output of a research project investigating 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 objective of this project has been to improve our understanding of how ongoing processes of technological upgrading, particularly automation, impact women's and men's employment and work in these industries. Our findings suggest that, in the short term, close to the introduction of new automation technology, the impact on employment takes the form of reassignment of workers directly involved in automated processes to other positions, tasks, and occupations. This study also explored the impact of automation in terms of work organisation and working conditions. Across the case studies, it emerged that the adoption of automation technologies has reduced heavy and repetitive tasks and improved health and safety for workers directly concerned by automation. Another interesting and related common finding is the reduction of workers' autonomy who are now subject to more standardisation of tasks together with an ongoing process of deskilling of operators. Finally, in the apparel and footwear sector, we did not find evidence of defeminisation at the establishment level as well as the automotive factories remains highly male-dominated. Cultural norms and stereotypes which influence not only the jobs women and men apply to and get hired for, but also which training and education they engage in, contribute to this gender segregation in both sectors.

Foreword

This report has been drafted jointly by the European Commission's Joint Research Centre and the International Labour Office. The report is part of a series of four joint publications that together represent the main final outcomes of a 2.5-year joint research project on the changing nature of work at a global level. The project, entitled "Building Partnerships for the Future of Work" was carried out by the two institutions as close implementing partners between January 2021 and June 2023 and was financed by the European Union's Partnership Instrument in collaboration with the European Commission's Directorate-General for Employment and Social Inclusion. In particular, joint research activities were developed under the project's Fact-based Analysis component, aiming to develop new evidence around some specific, and understudied, future of work themes focusing on aspects of relevance to the EU and selected non-EU countries. More information on the project and its other research findings is available here:

<https://www.ilo.org/employment/Whatwedo/Projects/building-partnerships-on-the-future-of-work/lang--en/index.htm>

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Executive summary

Fears over labour market disruption as a result of the adoption of new technology are not new, yet previous technological revolutions have featured both job destruction and creation dynamics and have not resulted in mass unemployment. The question today is whether this period of technological change will differ from previous ones, how it may change work and the labour force as we know it, and how it will affect different groups of workers, not least women workers, in different industries and contexts. Historically, automation has simultaneously triggered job destruction and creation. For instance, new technologies could result in fewer new hires rather than job loss, could result in the disappearance of some occupations as well as in the emergence of new ones, and could trigger job destruction in some sectors and the concomitant creation of employment elsewhere in the economy (Acemoglu and Restrepo 2018; Gregory, Salomons, and Zierahn 2019; Kucera 2017; Nubler 2016). As a result, instead of leading to higher long-term unemployment, technological change has previously been associated with shifts in workforce composition (Levy and Murnane 2005; Minian and Martinez Monroy 2018; ADB 2018; Nubler 2016).

More generally, despite the attention focusing on potential displacement impacts, this is just one of many dimensions by which automation affects work and employment. Technologies influence not only the number of jobs, occupations, and their task composition, but also conditions of work and employment, workers' autonomy, forms and dynamics of control, and industrial relations. That is to say that new technologies involve direct changes in how particular processes are carried out, including the physical and environmental requirements and conditions of work (Fernández-Macías 2018). But also indirect changes, including impacts on the contractual and social conditions of work (e.g. stability, opportunities for skills development, career progression and pay increases), and how workers and employers organize their relations and settle disputes (Fernández-Macías 2018). These less direct impacts related to human agency and social and organizational aspects of production are harder to determine, adding complexity to the analysis of technology impacts on employment (Fernández-Macías 2018; Fana, Villani, and Bisello 2022; Anzolin 2021; Fana and Villani 2023).

This report is the final output of a research project investigating 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 objective of this project has been to improve our understanding of how ongoing processes of technological upgrading, particularly automation, impact women's and men's employment and work in these industries. To the extent that employment outcomes are uneven across groups of workers, the project aimed at understanding the processes behind these outcomes and, in particular, whether they may reinforce or alleviate gender inequalities. The automotive and apparel industries have been chosen because despite being highly integrated in global and regional supply chains, they are at opposite ends of the spectrum in terms of automation and the gender composition of their workforce: employment in apparel manufacturing is highly feminized while women are much less prevalent in the automotive sector. Also, the automotive sector has the largest stock of robots in manufacturing and is often touted as being at the forefront of automation. Conversely, production processes in apparel manufacturing remain much more traditional and labour-intensive, particularly reliant on manual labour for sewing activities.

Despite these difficulties and challenges, the research setting provided the ground to explore different layers of heterogeneity and to take stock of similarities that emerged through the field interviews with workers employed in different occupations and stage of production involved and impacted, although to different extents, by the deployment of automation technologies within the establishments.

The case studies confirm that automation in both sectors has been an incremental process, with full automation not yet in sight. Especially within the automotive sector, during the last two decades no new wave of automation emerged. Moreover, recently, technological upgrade is mostly shaped by the introduction of digital technologies aimed at complementing existing automation technologies. In the apparel and footwear industry, significant technical bottlenecks to automation persist and labour-intensity remains high. Nevertheless, remarkable advances in automation were observed, particularly in the production of knitted apparel.

In both the automotive and apparel and footwear sectors, the deployment of automation technologies is driven by the need for enhanced output quality, greater efficiency, and, most importantly, higher productivity.

The two sectors also face similar barriers to technological upgrading, including technological limitations, costs associated with equipment purchase and maintenance, worker training, and idle time.

Focusing on the employment effects, our findings suggest that automation technologies have not immediately led to employment displacement in either sector, the automotive sector has experienced reduced employment over time through retirement plans and limited new hirings. In the medium and long run, employment reduction due to technological upgrading could emerge, although this is often mitigated by increases in volumes produced.

However, in the short term, close to the introduction of new automation technology, the impact on employment takes the form of reassignment of workers directly involved in automated processes to other positions, tasks, and occupations. This leads to a change in the composition of the workforce due to automation and technological advancements with a pivotal role played by maintenance workers. In line with expectations, these new jobs involve more likely engineers and maintenance workers whose share over total employment will likely increase in the future.

Besides these findings in terms of employment displacement and relocation, this study also explored the impact of automation in terms of work organisation and working conditions. Across the case studies, it emerged that the adoption of automation technologies has reduced heavy and repetitive tasks and improved health and safety for workers directly concerned by automation. However, at least in the automotive sector, better health and safety conditions only concern the physical aspect, like ergonomics, while mental health risks emerged in some cases because of increased work intensity, i.e., pace of work and saturation time. Another interesting and related common finding is the reduction of workers' autonomy who are now subject to more standardisation of tasks together with an ongoing process of deskilling of operators. Deskilling can be linked to lower specialized skills requirements for certain production jobs (e.g., workers in cutting in the apparel and footwear industry), as well as to the deployment of digital technologies which concentrate intellectual tasks at the top and middle management level. Moreover, digital monitoring of workers' performances also increases establishments' capacity to exercise indirect control and therefore reduce workers autonomy. However, the huge amount of information provided by digital technologies is not always analysed and therefore used at its potential. As it emerged from the interviews, barriers to exploit the data and information flow enabled by digital technologies are mostly based on economic considerations which apply to the short-term perspective.

The deterioration of workers' autonomy because of new indirect forms of controls and the high degree of standardisation induced by automation can also lead to the (re)emergence of classical forms of alienation. For instance, as reported by a worker in the apparel sector, this way of organising work allows her not to think how to do the job but just to mechanically follow instructions.

Finally gender segregation at the task level persists in both sectors despite technological advancements. Indeed, in the apparel and footwear sector, we did not find evidence of defeminization at the establishment level as well as the automotive factories remains highly male-dominated. Overall, in apparel and footwear, the workforce of the establishments studied remains feminized and while there are examples of women engaging in tasks traditionally performed by men, change has been limited and slow. Cultural norms and stereotypes which influence not only the jobs women and men apply to and get hired for, but also which training and education they engage in, contribute to this gender segregation in both sectors.

1. Introduction

Fernanda Bárcia de Mattos, Valeria Esquivel, David Kucera and Sheba Tejani

The *de facto* and potential implications of new technologies on work have been at the centre of public and policy debates. Research, especially that making headlines, has attempted to assess to which extent certain jobs and tasks are routine and repetitive, and therefore easier to codify and automate (see Anzolin 2021; Bárcia de Mattos et al. 2022). However, the large body of literature on the topic is not univocal: the relationship between robotisation and labour displacement has been put into question by recent studies, see Antón et al. (2022) and Klenert, Fernández-Macías, and Antón (2023). Less research has focused on understanding what is happening on the ground, at the firm level, using qualitative approaches (for a recent example, see Cirillo et al. 2022). From this perspective, technological feasibility is only one of many factors which shapes the adoption of new technologies. Prospects depend on many other elements such as the relative capital and labour costs, labour availability, skills requirements, infrastructure, logistics, and decision making at different levels and by different actors (employers, workers, managers, etc.) as well as the broader institutional setting where production takes place, including trade policies, the level and location of demand, and structural changes along the global supply chain (Bárcia de Mattos et al. 2022; 2023).

Fears over labour market disruption as a result of the adoption of new technology are not new, yet previous technological revolutions have featured both job destruction and creation dynamics and have not resulted in mass unemployment. The question today is whether this period of technological change will differ from previous ones, how it may change work and the labour force as we know it, and how it will affect different groups of workers, not least women workers, in different industries and contexts. More specifically, a key issue concerns the potential defeminization of the workforce which literature suggests often accompanies increases in capital intensity and productivity (Kucera and Tejani 2014; Tejani and Kucera 2021).

This report is the final output of a research project investigating 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 objective of this project has been to improve our understanding of how ongoing processes of technological upgrading, particularly automation, impact women's and men's employment and work in these industries. To the extent that employment outcomes are uneven across groups of workers, the project aimed at understanding the processes behind these outcomes and, in particular, whether they may reinforce or alleviate gender inequalities. The automotive and apparel industries have been chosen because despite being highly integrated in global and regional supply chains, they are at opposite ends of the spectrum in terms of automation and the gender composition of their workforce: employment in apparel manufacturing is highly feminized while women are much less prevalent in the automotive sector. Also, the automotive sector has the largest stock of robots in manufacturing and is often touted as being at the forefront of automation. Conversely, production processes in apparel manufacturing remain much more traditional and labour-intensive, particularly reliant on manual labour for sewing activities.

The project adopted a qualitative approach to explore the complexities surrounding decisions to automate production processes and impacts on work and workers. It is built on in-depth case studies in selected manufacturing factories, including site visits and interviews with employers and workers. The following sections presents the motivation for this research project and its methodological strategy. Chapter 2 examines the outcomes of the case studies on the automotive industry. Chapter 3 presents findings from the research on the apparel and footwear sector. Next, cross country and cross sector insights are discussed, and conclusions are presented.

Background and motivation¹

There has been a lot of discussion around Industry 4.0, a concept which encapsulates a wide range of new and integrated physical and digital technologies in manufacturing which are transforming the organization of production processes. While it is difficult to untangle innovations which integrate into existing systems and which complement one another, this project specifically focuses on automation processes and their impacts on automotive, apparel and footwear manufacturing. To this end, we define automation as the replacement of labour input by (relatively autonomous) machine input for the performance of some tasks in production processes (Fernández-Macías 2018, p.16). However, acknowledging the great variation in technological development and implementation across industries and countries, and particularly the limited automation in production processes of the apparel and footwear industries, the project also focuses on technological upgrading more generally, defined as the introduction of machines, tools and processes which increase labour productivity.

There is no doubt that new, and constantly evolving, technologies are increasingly able to perform work previously done by workers. Yet the impacts of technological change, including automation, on employment and work remain uncertain. Some studies examining empirical data find that automation is labour-displacing (Acemoglu and Restrepo 2017; Chiacchio, Petropoulos, and Pichler 2018), while others do not associate technology adoption with negative employment outcomes (Dauth et al. 2017; Graetz and Michaels 2018; Autor and Salomons 2018). Assessments of the potential employment impacts of technologies based solely on technical feasibility and task characteristics tend to indicate high risk of worker displacement – particularly for workers whose job feature predominantly routine repetitive tasks (Frey and Osborne 2013; World Bank 2016; McKinsey Global Institute 2017; Arntz, Gregory, and Zierahn 2016; Nedelkoska and Quintini 2018). However, technical feasibility does not necessarily translate into widespread adoption. Rosenberg (1976) distinguished economically relevant technologies, defined as those that are diffused in productive systems, from those that are not diffused due to impediments of different types, such as demand constraints, supply bottlenecks, and machine tools' lack of complementarities. Moreover, processes of automation tend to be much more incremental than suddenly disruptive of the *status quo*, not the least because technical feasibility does not automatically imply economic feasibility, which varies across sectors, firms and countries (Acemoglu and Restrepo 2016; Staccioli and Virgillito 2021). Furthermore, automation often relates to specific tasks within bundles which constitute jobs, such that automation impacts jobs' task content but does not necessarily lead to their disappearance.

Historically, automation has simultaneously triggered job destruction and creation. For instance, new technologies could result in fewer new hires rather than job loss, could result in the disappearance of some occupations as well as in the emergence of new ones, and could trigger job destruction in some sectors and the concomitant creation of employment elsewhere in the economy (Acemoglu and Restrepo 2018; Gregory, Salomons, and Zierahn 2019; Kucera 2017; Nubler 2016). As a result, instead of leading to higher long-term unemployment, technological change has previously been associated with shifts in workforce composition (Levy and Murnane 2005; Minian and Martinez Monroy 2018; ADB 2018; Nubler 2016).

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¹ This section hails from two background papers prepared within the framework of this research project, namely Anzolin (2021) and Bácia de Mattos et al. (2022).

adding complexity to the analysis of technology impacts on employment (Fernández-Macías 2018; Fana, Villani, and Bisello 2022; Anzolin 2021; Fana and Villani 2023).

Matters linked to social structures may be of particular concern when viewed through a gendered lens, given that findings from a growing body of literature suggest that automation produces uneven employment effects for women and men. Fana, Villani, and Bisello (2021; 2022) find gender asymmetries regarding work organization and distribution of power at the workplace, with disparities related to autonomy and authority, in addition to differences in the task attributions of women and men in similar jobs even after controlling for characteristics such as education and seniority. Furthermore, several empirical studies show that manufacturing sectors with a high proportion of women workers experience defeminization as production becomes more technologically advanced (Tejani and Milberg 2016; Tejani and Kucera 2021; Seguino and Braunstein 2018; Caraway 2006; Kucera and Tejani 2014). In regard to the manufacturing of motor vehicles, apparel and footwear specifically, Tejani and Kucera (2021) find a negative association between labour productivity increases and women's employment within these industries.

This outcome has been attributed to the systematic effects of gendered norms and institutions in the economy. Among the hypotheses put forth in literature are the lesser importance of low-wage women's labour in more capital-intensive production; norms which define men as primary workers and women as secondary workers; and the different skills requirements of new industrial jobs combined with the supposedly different skills of men and women (Tejani and Milberg 2016; Tejani and Kucera 2021; Seguino and Braunstein 2018; Caraway 2006; Kucera and Tejani 2014). For instance, breadwinner norms tend to award men with higher value-added jobs that have the potential for wage increases while women, considered secondary workers, are preferred for labour-intensive jobs. Gender stereotypes about workers' abilities, or notions of "feminine productivity", around women's suitability for labour-intensive, routine and manual work (Salzinger 2003) may disadvantage women during technological upgrading. Institutional factors such as gender segregation in vocational training and technical education place women at a disadvantage even before they enter the labour market and intensify unequal outcomes in the context of automation (Tejani and Milberg 2016). This literature pinpoints the need to examine how technological upgrading of industrial processes, including automation, interact with local social structures, cultural and institutional systems, as well as with industrial relations and workplace organization systems to produce uneven gender employment outcomes.

Research directly exploring evidence for the competing hypotheses outlined above is scant, and little is known about the decision-making processes behind these gendered outcomes, including the role of different actors and institutions in shaping them. There is also limited research evaluating the gendered impacts of automation in specific industries and how this may vary according to the capital intensity of production, the amenability of production to automation and the prevalence of women in the workforce. In addition, perhaps largely due to data availability (or lack thereof), there is a dearth of evidence on important employment aspects which are difficult to assess and quantify. This includes, for instance, concerns over employment relationships and several dimensions of working conditions which may be directly or indirectly impacted by changes in work processes and technological upgrades. Moreover, most existing evidence relates to advanced economies, with few contributions on developing countries, despite the heterogeneity in productive structures and institutional factors. This project attempts to address some of these knowledge gaps.

Methodology

The main goal of this research project has been to gain a better understanding of how processes of industrial automation and digitization impact production processes, working conditions, jobs, task profiles within jobs, and the socio-demographic profiles of workers, with particular regard to gendered impacts. More specifically, this research project has aimed at investigating: (i) which have been the main drivers and barriers to technological upgrading and automation in the industries under study?; (ii) has the adoption of new technologies resulted in changes in employment, working conditions, tasks and work organization, and industrial relations?; (iii) have women and men workers been affected differently by technological upgrading, and if so, how?

Countries covered by the study have been selected so to exploit institutional differences that may affect both the adoption of automation technologies and its impact on work and employment. Furthermore, attention has been paid to the position of the different countries along the automotive regional and global value chains which again plays a role in shaping technological upgrades and their effects on the labour market.

The research was structured in three phases. First, technical specifications for the case studies were developed by the EC-JRC and the ILO. These were used to select a team of experts to work on specific country-sector pairs. A research consortium was selected to conduct the work in the European countries, and independent experts were selected to conduct the research in non-European countries. Following this initial phase, in line with the qualitative research design, researchers started the selection process of firms for case studies. This was a two-stage process. First, researchers identified a list of potential cases – the goal was to identify companies which had taken relevant steps in technological upgrading and automation, thus constituting a type of purposive sampling known as extreme case sampling (Etikan, Musa, and Alkassim 2016). This involved desk research to gather background information on various firms as well as, often, informational interviews and contacting companies regarding potential participation in the project. From this tentative list, the researchers, in close collaboration with the in-house research teams at the EC-JRC and the ILO, selected the firms (i.e. factories) which would constitute the case studies. Two establishments per country-sector pair were selected.²

The factory case studies were based on semi-structured interviews conducted between June and December 2022. Interviews were conducted face-to-face and accompanied by site visits whenever possible. However, there are some exceptions. In Indonesia, restrictions related to the global pandemic prevented access to automotive manufacturing plants, thus impeding site visits and resulting in online interviews. In Germany, it was not possible to access factories and sectoral experts were interviewed instead. The interviews were undertaken on the premise of anonymity, for firms and individuals, in the reporting of research findings.

Interviewees were selected by the firms, based on pre-defined profiles. These included managers, workers' representatives, and workers, including technology specialists within the firm.³ A set of interview guidelines was developed by the in-house research team in collaboration with country experts, for use across countries with small adjustments based on the local context. Interviews followed semi-structured guidelines tailored to each interviewee profile. Discussions with managers and technology specialists encompassed the topics of technological upgrading and automation, technology and workers, and general prospects for the future. Worker representative interviews focused on industrial relations and dialogue, technological upgrading and automation, technology and workers, working conditions, training and career tracks. Topics for workers' interviews included workers' tasks, technology and workers, working conditions, training and careers prospects, as well as home and work. Gender dimensions were included across all topics and the gender composition of interviewees was managed to secure the representation of women.⁴

This qualitative research design implies limitations in the interpretation of findings. The small sample size and firm selection strategy prevent us from generalizing results to the global automotive, and apparel and footwear industries as a whole. Furthermore, as mentioned, informants were selected by the establishments and interviews were conducted at the place of work, which could have affected interviewee responses. Additionally, the research project was designed before the onset of the global COVID-19 pandemic but was conducted during the crisis such that the research did not take place in a business-as-usual context. With these limitations in mind, we are confident that this research project makes a robust contribution to the knowledge base on the multi-layered impacts of automation technologies on work and employment. We hope our findings will inform social dialogue and employment policies towards workable and sustainable solutions to some of the key challenges related to the future of work.

² Except for the apparel and footwear sector in Mexico and Indonesia, for each of which four establishments were selected.

³ Except for the automotive sector in Germany, as previously noted.

⁴ Fieldwork guidelines and the full set of questions are available from on request.

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2. Automation and employment in the automotive sector: Findings from case studies in Germany, Indonesia, Mexico, Romania and Spain

Marta Fana, Guendalina Anzolin

This report will provide insights on a cross country study of automation drivers and its effects on employment and production in the automotive value chain. The focus on this specific industry is motivated by the fact that automotive has often been the bedrock of manufacturing automation advances due to its high-volume production, high value-added processes, high levels of standardisation and modularisation that allowed the deployment of advanced technologies. The focus on automation is motivated by the intention to better understand whether and how new automation technologies are having a disruptive and revolutionary impact on how work and production are organised, both within the firm and along the value chain. In fact, even though automation has been a reality for more than 70 years – the first robotic arms were deployed in industrial production in the 1960s – recent evolution in terms of advanced robotics, 3D printing, Internet of Things, Virtual Reality are calling for a new analysis.

During the past decade, there has been an accelerating trend of digitalisation in the automobile sector, which is entrenched with increasing connectivity (De Propris, 2020). Although the issue of connectivity has been less prominent in the empirical literature, it is crucial in terms of value-creating mechanisms for businesses (Cirillo, Rinaldini, Staccioli, & Virgillito, 2021). Despite being an essential prerequisite of Industry 4.0, digitalisation – which is the foundational element of increased connectivity – is not what is ‘new’; rather, the novelty of recent technologies, the so-called Industry 4.0, is the fusion and interconnection between different technologies across the physical and digital domains, which aim to create cyber-physical systems⁵ (Andreoni, Chang, & Labrunie, 2021; Martinelli et al., 2021). Combining different technologies is not something new; technologies always evolve in systems, often with technologies coming from different realms of productive systems. However, in comparison to previous waves of technological change, Industry 4.0 systems are characterised by a higher level of complexity and interdependency between traditionally separate fields of knowledge. Moreover, investments in I4.0 technologies have a positive impact on firms’ productivity (Benassi et al., 2022)

Empirical evidence on the adoption level and the impact of automation technologies is scarce. First of all, there are very few datasets that allow quantitative studies on the topic; the International Federation of Robotics is the only source that collects granular data (at the country and sectoral level) on the adoption of industrial robots across the world, and they are classified in a way to be matched with employment data. Secondly, qualitative studies offer multiple insights as they are better able to capture the complexity around automation and its multifaceted impact on employment and production. The case studies presented in this report contribute to such emerging qualitative literature on the diffusion and the impact of automation technologies. As most qualitative approaches, a series of challenges emerged while conducting the data gathering process in five different countries because of the high heterogeneity both at the firm level (even when considering the same segment of the value chain, e.g., OEMs, tier 1, tier 2/3, etc.) and at the country level where firms are embedded in a complex net of institutional and cultural elements that shape the ‘way of doing business’ and thus the opportunity to adopt new technologies. Finally, it has to be acknowledged that the research was conducted in 2022, therefore it was affected by the long wave of COVID-

⁵ Cyber-Physical Systems (CPS) are defined as collaborating computational entities which are in intensive connection with the surrounding physical world and its on-going processes, providing and using – at the same time – data accessing and data processing services available on the internet. Within these processes, the interaction between physical and cyber elements of key importance.

19 and in particular by the restructuring and reorganization processes that COVID-19 entailed at company and sector level

In this report, we will present eight in-depth case studies across five countries that operate in the automotive sector, at different stages of regional and global value chains. These countries are Germany, Mexico, Spain, Romania, and Indonesia. These case studies look at different actors of the value chain, both OEMs and suppliers that operate with different components. The case studies reveal aspects on automation technologies' drivers and obstacles, while also presenting insights on the impact of automation technologies on the production process and along the value chain, as well as on employment, work reorganisation and labour process. Our findings reveal that different organisations of production, regulations, and culture play a pivotal role not only in the decision of adopting automation technologies but also in the effect of these technologies on labour – i.e., reorganisation of tasks and occupations – and on gender.

[Section 2](#) of the report will present a brief overview of automotive sector in each country and will introduce the case studies. [Section 3](#) presents the findings of the research and specifically the level of automation technologies adoption in each plant examined, the main drivers for automation as well as obstacles/bottlenecks. [Section 4](#) discusses the impact of automation on the organisation of production and on employment, with a specific focus on the gender dimension. [Section 5](#) concludes with detailed references to policy implications and future research opportunities.

Case studies: overview of countries and sectors

The focus of the case studies is on the automotive sector of five countries: Germany, Romania, Spain, Mexico, Indonesia. Crucially, these countries are all linked to regional and global automotive value chains, yet at different levels and with different intensity and value adding contributions. While Germany lies at the core of the automotive global value chain, where a lot of value-adding activities are performed, Romania and Spain are more peripheral, albeit well-placed in the European division of labour. Mexico is strongly tied to the North American market and occupies the lowest value-added segments of regional production chains. Indonesia has recently gained increasing importance in the ASEAN automotive value chain. See [Table 1](#) for an overview of the importance of the sector in each country.

Table 1. Overview of the automotive sector in the five countries considered in the study

Country	% of country GDP	Employment (units of thousands)	Automotive Export over Total Export	Volume produced (units of thousands) ⁶
Germany	4.7 % ⁷	800 ⁸ (up to 2200 including upstream and downstream)	16.8 % (2019) ⁹	4600
Romania	14 % ¹⁰	180 ¹¹	26 % ⁷	490
Spain	11 % ¹²	212 ¹³	18.9%	2800
Mexico	3.5%	100	7.6%	4000
Indonesia	4%	1500	5.3%	1300

Source: Data is taken from the country case reports delivered to JRC, when it is not specified.

In each country, the initial idea was to select two final assemblers (from now on OEMs) and to conduct multiple interviews within each of them. Six OEMs were interviewed, two in Romania, two in Indonesia and two in Mexico. In Spain, although numerous OEMs were contacted, there was high reluctance to discuss the topic at the core of our research. Instead, the research group managed to interview two suppliers (one Tier 1 and one Tier 2). In Germany, despite several attempts on different levels, it was not possible to access any plants. Both for Germany and Spain, the critical juncture determined by overlapping crises of the COVID-19 pandemic, as well as the recent war-related constraints on energy and raw materials, created major obstacles to engage directly with OEMs. [Figure 1](#) summarises the different players interviewed at different levels of the automotive supply chains. A total of 86 interviews were conducted across firms in [Figure 1](#) and within the German expert ecosystem (10 interviews), encompassing workers in different departments to ensure a more comprehensive understanding of the phenomena at stake. Such workers included: managers (i.e., human resources, sales, production, production chemistry, automation and logistics, automation and quality, information system), engineers and technicians, union representatives, production leaders, maintenance coordinators, assistant production managers, head of new projects and robotisation across different departments. In terms of work composition, it was challenging to include blue collar workers, while in terms of gender composition it was hugely skewed towards male workers (15 out of 86 interviews).

⁶ Available at www.oica.net/category/production-statistics/2019-statistics/

⁷ T. Puls and M. Fritsch, Eine Branche unter Druck– Die Bedeutung der Autoindustrie für Deutschland, op. cit.

⁸ The Automotive Industry in Germany – German Trade and Investment (GTAI) Report, Issue 2022/2023

⁹ Fakten zum deutschen Außenhandel, Bundesministerium für Wirtschaft und Energie (BMWi), September 2020, available at: www.bmwi.de.

¹⁰ Emanuela Cristescu, « The automotive industry in Romania », SMMT, 2021. <https://www.smmt.co.uk/2021/08/the-automotive-industry-in-romania/>

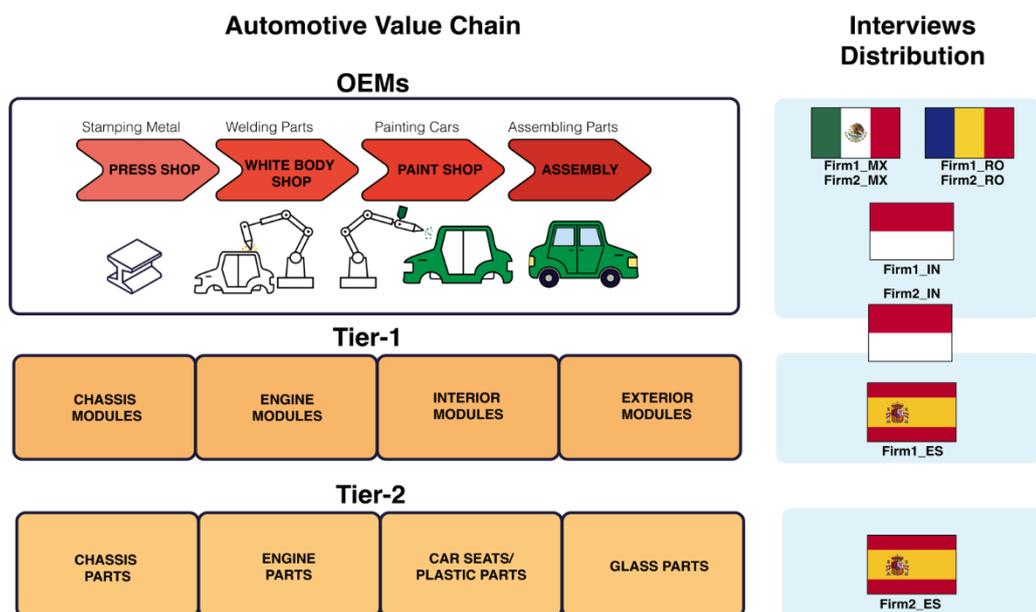
¹¹ European Automobile Manufacturers' Association 2019a, 11ff.

¹² ANFAC (National Association of Automobile and Truck Manufacturers) - 2019

¹³ Strong impact of Coronavirus on the Spanish automotive suppliers. Sernauto.com. <https://www.sernauto.es/en/sala-de-prensa/noticias/fuerte-impacto-del-coronavirus-en-la-industria-de-componentes-de-automocion>

As a result, the interviews cover a broad spectrum of production ranging from auto parts to different assembled vehicles. **Firm 1 (Firm 1_ES)** in Spain produces car seats padding for an Opel's tier-1, while **Firm 2 (Firm 2_ES)** is specialised in bodywork, providing bending, stamping and welding of subassemblies of car's structural parts. Indonesia's **Firm 1 (Firm 1_IN)** is an OEM assembling mainly Sport Utility Vehicles (SUVs), whereas **Firm 2_IN** provides structural car parts to Firm 1_IN, and assembles vehicles for the domestic Indonesian market. In Mexico, **Firm 1 (Firm 1_MX)** produce two models, and **Firm 2 (Firm 2_MX)** produces a specific set of models, including electric and plug-in versions. Finally, **Firm 1 (Firm 1_RO)** produces five models and **Firm 2 (Firm 2_RO)** produces two models.

Figure 1. Interviews along the automotive supply chains



Case studies findings: drivers and bottlenecks

The findings of the case studies are highly heterogeneous, with product specific and location specific elements that influence the observed dynamics of technology adoption as well as its outcomes and impact on production and workers. As described above, we will present findings of six OEMs (in Mexico, Indonesia and Romania) and two suppliers in Spain.

The first level of heterogeneity observed in the automation technologies is mainly related to the types of technologies adopted by companies. Crucially, this is strongly determined and tailored to the specific type of product/commodity that is produced. However, also the overall organisation of production and the level of flexibility that the plant has or aims to have plays a role in determining which type of technology to implement (Anzolin & Andreoni, 2023). Hence, before delving into the details of case studies findings, we give a summary of the main technologies adopted in the different plants across the five countries.

Romania

- **Firm 1 RO:** The plant reports high levels of automation for the stamping department and assembling department.

- Firm 2 RO: The plant operates with partial automation of stamping, welding, painting the base and automatic tooling in the engine shop.

Spain

- Firm 1 ES: The plant has completely automated the chemistry area: robots are used to inject mixture, optical viewers are used for positioning in the mould, and boxes are automatically filled by product types.
- Firm 2 ES: The plant has a high level of automation. It presents a highly functional layout at the shopfloor level which is the result of the creation of a digital twin of the production process aiming at an effective production flow to enhance, among other objectives, the implementation of AGVs and of a Manufacturing Execution System (MES), which are the most recent automation technologies introduced.

Mexico

- Firm 1 MX: The plant introduced a high-speed stamping press and introduced new controllers and robots for handling components for stamping. Also, a new broadcast system is used with 19 suppliers, and it facilitates the just in time organisation of production.
- Firm 2 MX: The plant operates with a partial automation of stamping, bodywork, welding. On the other hand, painting is fully automated. Recently, automated vision systems robots to detect weld burrs were introduced.

Indonesia

- Firm 1 IN: In the plant, all the warehouse activities are fully automated and digitised, in an 'e-kanban' system. Furthermore, IoT based monitoring environments comprising sensors, diagnostics and trends are widely used. Soon to be implemented the digital twins to optimise the entire production process
- Firm 2 IN: Automation in every department of the OEM plant was reported, from stamping to painting and assembly. From 2015, it increased from 40 per cent to 80 per cent. The company introduced also the 3D simulation to support the design of modern auto vehicles through advanced virtual engineering methods¹⁴.

Finally, in **Germany** it was not possible to access plants. However, interviews with experts reveal that the level of automation has been pretty stable in the last few years. In the automotive sector, automation levels are generally high, but this is strictly related to the phase of the production process. One of the experts reported:

First of all, the degree of automation in the automotive industry is rather high compared to other industries. So the first industrial robots at the Wolfsburg plant were introduced in something like 1961. So there is almost 60 years of experience with automation (...). If you look at the production areas, there is no unified picture: in some of the Body Shop (the part in which metal is formed in the chassis of the car) we have a degree of automation around 90 per cent. (Thymian Bussemer, DEU)

Insights from the interviews in Germany also confirmed that there are pivotal projects undergoing, which aim at exploring more advanced digital production technologies, such as augmented reality. Apart from that, the stakeholders interviewed agree that *"a peak of technical development has been reached and there is no progressing at the moment"*.

¹⁴ These tools offer the possibility to design components through digital 'mock-up' processes reducing time, errors, material waste and thus costs in production.

Drivers

During the data collection process, one of the focal points of attention was on the drivers that lead firms to adopt automation technologies in the industry. Understanding the real drivers of automation is a crucial aspect not only to design and implement informed industrial policies (i.e., by fostering conditions for automation technologies adoption or by helping in removing the obstacles for their adoption), but also to better face unbalances that may be created by automation technologies. The case studies confirm, and extend, existing literature on the topic particularly emphasising two aspects: (i) automation is a matter of economic and production feasibility; economic feasibility can be articulated in different ways, in particular, (ii) technical drivers (i.e., related to the technology itself - e.g., the quality of the product - and the production process) and workers' related factors (i.e., ergonomics and reduction of heavy tasks) are important drivers across the different case studies. The rest of this section will review these aspects.

Economic and production drivers

Adopting automation technologies is first and foremost an economic choice; in other words, when adopting new technologies, the management intends to increase productivity and lower costs. Crucially, this can be achieved in different ways, such as faster production paces, decreased defects and thus scrap rate, increased efficiency, improved quality of the production and yields an overall economic value out of the investment.

For plants in Mexico, productivity, consistency, efficiency and quality were mentioned as drivers. In Romania, the focus was reported to be on increasing efficiency of the production process through cost reduction (e.g., by reducing through cutting labour costs, investment, reorganisation of the production process, maintenance costs, etc.). In the case of Spain, suppliers confirm that costs are the main drivers especially at the supplier level, where additional dynamics – related to the position of these companies in the value chain – unfold because of technology-led cost reduction. For instance, in the case of the Spanish supplier *Firm 2_ES*, the technology-led reduction of labour costs has been described as an essential requirement for attracting new investment from the parent company. Specifically, this can take the form of either e-mobility upgrades or plant modernisation to better integrate them into the digital transformation network. Interestingly, a further example where such dynamics are even clearer is the latest agreement between an OEM and unions in Spain, where the parties agreed that for the next three years there will be no wage increases, but there will be an additional investment to secure the production of OEM's electric vehicle in Spain, to the disadvantage of the Cologne plant. At the supplier level, it also emerged that it is becoming more important to improve the traceability of the production process.

A final point concerns the impact of the COVID-19 pandemic, which forced companies to find alternative ways to keep on producing, thus acting as a major driver for further digitization and automation, especially in Indonesia and Mexico. In *Firm 1_IN* in Indonesia, the automation rate in the welding section rose from 38 per cent to 50 per cent between 2019 and 2022 and they reported that this was largely driven by the pandemic. Both, *Firm 1_IN* and *Firm 2_IN* reported that they advanced significantly in developing their E-Kanban system¹⁵ and managed to digitalise almost entirely their systems related to warehousing including ordering, purchasing, and monitoring of stock between 2020 and 2022, in order to have better and more consistent monitoring. Rapid digitalization was necessary to allow for more remote work and a flexible reorganization of key production processes.

Technical drivers and workers' related factors

Obviously, workers matter a lot when the decision to adopt new technologies is even considered. Importantly, the skills level of the workers must be adequate not only to use the machine but also to improve them and face possible everyday challenges. Collaboration between human workers and technology can bring essential improvements to the quality of production. In the case of both Indonesian firms, increases in the quality are required by legislation (namely, automation is expected to improve the quality of production and to bring the end-product in line with the

¹⁵ See: <https://www.investopedia.com/terms/k/kanban.asp>

required environmental and safety standards). More notably at the assembly level, quality improvement through error free assembly and efficient material supply are driving the adoption of new technology. This was observed in the Mexican case study, where management of the use of materials in the production line has been improved with error-proof “poka-yoke” devices that have been incorporated using barcode readers and “pick to light” devices. Here, technicians interact with the automated assembly line through these two methods. However, the adoption of these technologies does not neglect the needs of workers. Instead, before a new technology is introduced, affected employees at *Firm 1_MX* and *Firm 2_MX* plant are expected to reach consensus, and each area is required to give their approval.

Furthermore, workers matter because several jobs involve tasks that are challenging and exhausting to perform (both physically and mentally), e.g., heavy lifting and highly repetitive tasks that can be alleviated by new technologies, thus allowing to redeploy the workers in the plant. Along these lines, ergonomics and safety are found to be a significant driver of automation technologies adoption. For example, levels of exposure to risks or to mental overload (i.e., burnouts), dirty processes tend to be automated in the two OEMs interviewed in Mexico. Similarly, in Romania there is a strong focus on improving the ergonomics and safety at work to enhance work efficiency (therefore combining this driver with the economic argument described above). This is achieved through the reduction, if not elimination, of heavy, repetitive, dangerous and harmful tasks. Notably, it was generally observed across most of the interviewed plants how it was possible, through automation, to improve ergonomics for individual tasks, reducing the risk of heavy (as in the case of loading large sheet metal parts for stamping), dangerous (as in the case of welding), harmful (as in the case of painting) and repetitive tasks (as in the case of certain assembly operations).

A further element is related to the fact that new technologies are highly defined by the type of product produced in each plant. Whether a company produces steel metal sheets, or headrests and carpet, this affects the type of technologies as well as the level of automation that is technically and economically feasible. In this study, this is particularly clear for the two suppliers studied in Spain. For *Firm 1_ES*, most of the automation technologies have been adopted in the chemistry area and thus are very specific to that type of process (e.g., optical viewers or automatic injecting mixture machines). For *Firm 2_ES*, a company active in the production of metal components, price competition is the main driver for automation technologies, and it can only be achieved by reducing cost per unit of output.

Don't forget that we are a production factory with a focus on processes [on metal products], so we must take in account to reduce cost, cost, cost... [Firm 2_ES_1]

For final assemblers – such as *Firm 1_MX* in Mexico and both OEMs in Indonesia – consistency, problem-solving and the necessity to cope with a more-than-ever volatile consumer market underlie the adoption of technologies and in particular of digitalisation. Setting up factory information systems and automating the material logistics and administration is crucial in making this type of production more resilient to changing external conditions. Thus, for OEMs, it is the types of process and the challenges at the organisational level that call for certain types of technologies.

To conclude the discussion on drivers, interestingly, environmental drivers were only mentioned in the case of *Firm 2_MX*, with specific reference to the painting shop – with reference to water consumption.

In the painting area, new material technologies were introduced for the metal surface preparation area. The application booths were fitted with the latest technologies, which made the paint emission control management application more efficient. In the spray booths, for example, we do not use water to capture excess applied paint; The entire vapour extraction and control system is dry, therefore we have zero gas emissions into the atmosphere, and we also have zero disposal of hazardous waste. [Paint group manager, Firm 2_MX_1].

Bottlenecks

Given the highly heterogeneous nature of automation technologies, and the general dependence of automation on economic and technical factors, our case studies provide a wide perspective on different possible bottlenecks hindering technology adoption, with some of them that correspond to the absence of some of the drivers discussed in the previous section, and some others that are more standalone issues that materialise. Altogether, four main and recurrent obstacles could be identified as key constraints.

Financial constraints

Interestingly, balancing the budget while introducing automation is a challenge even at the OEM level, where there is more space to leverage financial resources. Challenges arise because – as reported by the Mexican OEMs – adopting new technologies, reshaping platforms and upgrading existing technologies is a tremendously expensive and capital-intensive project. Furthermore, given the multinational nature of these assemblers each plant competes with other affiliates to secure resources for business expansions, thus imposing additional caution on the choices of projects. Similar financial constraints were also mentioned by the Indonesian factories. These considerations apply even more deeply to suppliers: Spanish *Firm 2_ES* mentioned that credit availability and possible subsidies at the country level are important variables to make the decision to automate. However, the search for funding comes along with the idea of the investment project.

Technical skills and know-how

Half-way between the lack of skills and technologies whose implementation is not optimised, *Firm 2_ES* reported a bottleneck regarding the challenge to elaborate on the huge amount of data that new technologies produce. For example, manufacturing execution systems, as well as e-kanban systems, produce enormous data flows, which have to be both well-managed, and interpreted. Consequently, proper strategies must be put in place:

We introduced the technology so far but we are still training our shift leaders to make the interpretation of the data, because introducing the technology is relatively faster, but, implement, half year, running.
[*Firm 2_ES_1*]

This consideration does not apply only to suppliers but also to OEMs. Similar constraints on data-production related challenges were mentioned by the two Mexican OEMs. There, engineers are being encouraged to mine data to start getting involved in its use for continuous improvement projects. Interviewees at *Firm 1_MX* recognized data mining as a significant challenge. New technologies are creating millions of data points, and their use and analysis require much effort, knowledge, and creativity, particularly on the part of engineers and system experts. As such, a specialised area may be required in the near future. Within *Firm 2_MX*, a company more in line with the ‘continuous improvement’ philosophy, engineers are already starting to work on it.

That is the improvement mindset, if the engineers have time, they can search for these solutions, the data is there already, but we need to dedicate the time to the analysis of information. [*Assistant Plant Manager, Firm 2_MX*]

The management culture plays a key role in determining how these training challenges are dealt with. As reported by interviews in Indonesia, the lack of support from management is identified as a primary factor hindering the implementation and progression of automation technologies. Namely, for these technologies to be operational and well-implemented, the workforce constantly needs training. The absence of support from management on these training programs, possibly dictated by financial consideration reasons, makes full automation not yet viable in this country. Therefore, the question of the number of skilled workers within the overall workforce (which for instance in Indonesia tend to migrate) becomes central in determining the adoption and effective implementation of new technologies. Even though this could appear as a developing-country-specific bottleneck, similar considerations were reported from interviews in Spain. Interviews at the Spanish *Firm 2_ES* plant reveal that the qualification of the workers is currently too low to allow them to control and intervene on underperforming machines, thus leaving the burden on team leaders.

Technical complexity and infrastructure requirements

First, technical bottlenecks arise when new technology cannot fully satisfy the specific conditions imposed by the production processes or issues linked to the existing infrastructure, thus becoming less attractive. For instance, both in the Spanish *Firm 1_ES* and *Firm 2_ES* plants, difficulties in the day-to-day implementation were mentioned as a crucial bottleneck, which combined with financial considerations, has been hindering the adoption of new technologies. Similarly, both OEMs in Indonesia, mentioned the strong dependency of automation on the existing conditions at the factory. Namely, given the incremental and gradual nature of automation adoption processes, automation steps must be one step on the top of the other. This incremental nature therefore demands having solid foundations before going for full automation. Interviewees at the Indonesian plants, despite strongly emphasising automation and digitalization, mentioned how existing infrastructure is a paramount issue. Specifically, power outages and other types of electricity disruptions lead to increases in production costs and hamper automation to its core. A key informant in one of the two companies in Indonesia reported that:

Automation requires the right eco-system. It does not work without the necessary infrastructure. [Key Informant_Firm 1_IN]

Overall, the case studies point to the need to tackle many technical challenges at the firm level before moving to full or partial automation. Automation requires significant investments in infrastructures, such as robots and computer software.

Second, technical bottlenecks related to the IT infrastructure were also raised during interviews in Germany. Here, interviewees stressed the complexity of integrating the uncoupled IT infrastructures in one cloud-based system (Butollo & Schneidemesser, 2022; Krzywdzinski, 2021a). Requirements to deal with various IT systems, some built in house, others legacy systems have been reported to increase the complexity of the digitalization. However, we must note that the study on Germany is distinct from other studies. Owing to COVID-19 related restrictions for plant access, interviews were conducted with experts of the automotive sector in Germany. Insights from these interviews focused on the importance of looking at technologies in a comprehensive way, for example understanding the complementarities between the adoption of digital technologies and the conversion to e-mobility since the two processes are strongly linked. German plants (for instance, OEMs) currently operate with extremely high levels of automation, not only in the bodyworks but also in parts of the assembly line. However, insights from the interviews stress how complex it is to reach full automation, and in some areas – like final assembly – automation is not technically feasible and it did not progress as fast as expected. Indeed, according to the interviews often the production department stated that no more automation was desired due to high-cost intensity and lack of flexibility – that humans have.

If you look at other areas, like final production (this is where those famous assembly lines are being installed) automation is far lower because there the majority of work need to be done where it's necessary to go into the car: you do still need human craft because it's far too complicated. Robots are too inflexible, too heavy in order to do this kind of work. So there's a rather high intensity of human labour in the last area of the production process, in other areas of production, it's rather high (Thymian Bussemer, DEU)

Third, and complementing the points above, a further technical aspect is related to how automation technologies are adopted. This tends to happen in a 'retrofitting way', meaning that new machines/sensors/software are integrated into existing production facilities that have been in place for years (when not decades) and which are difficult to 'automate' and 'digitalise' because they were not programmed to do so. For example, in Indonesia, *Firm 1_IN* is already overseeing multiple machine maintenance processes through the Internet of Things – which pulls data from sensors and machines – to see diagnostics and trends related to machine operation and/or process. However, the process is complex to extend to the overall plant because old machines that were bought in the 1980s-1990s are not yet digitally connected. Serious innovative efforts are undertaken to link these machines to the company's digital platform.

Limitations of existing automation technologies

Technical bottlenecks may be related to the specificity and complexity of tasks addressed by automation. For instance, in the Spanish case, an interview at *Firm 1_ES* identified the difficulty in the faced problem (i.e., elimination of deburring operation by preventing the escape of foam from moulds) as a currently insurmountable task for robots.

'for a robot [deburring] is a very complicated task. We have tried, but we haven't [yet- editors' note] managed to avoid the burr in the mould. We have been working on a mould that doesn't produce burrs, but so far it hasn't been possible.' [*Firm 1_ES_3*]

The presence of these tasks which are complicated to automate would therefore require a high degree of customization in robots and digital production technologies. Yet this is not easy, as the Indonesian *Firm 2_IN* reported that often imported machinery and robots are not made to cater for the specific needs of the production facility and/or to produce specific types of vehicles or models that are produced by the plants, so they would need to customise, which is difficult and requires a lot of retrofitting capabilities.

It's hard to customize according to what we want. We are forced to follow what the robot manufacturers can supply. Often what we want and need does not meet their platform or system. [*Key Informant, Firm 2_IN*]

Interestingly, the lack of flexibility of automation technologies was reported to be a technical bottleneck – compared with the greater flexibility of human workers – hindering full automation. As reported in *Firm 1_RO*, there will not be a significant increase in the degree of automation because of the very high diversity/variety in the plant and the higher flexibility of human labour, which prevents a high enough return on investment. Analogously, German expert interviewees reported that [given the cost intensity of these projects] by the end of the day, humans are more flexible. So, when changes to the production or produced models occur, humans are still better than machines.

Difficulties in the re-organisation at the shop floor level

As evidenced in the Romanian case study, managing the relation with technology providers and the development of automation software is challenging; both plants reported the need to enlarge their facilities to meet the need of growing space to deal with automated technologies. From the case studies, it clearly emerges that adopting automation technologies, both hardware and software, often requires a reorganisation of the production process. *Firm 1_RO* reported that they rationalised the shop-floor space to allow not only room of manoeuvre, safety conditions of work (right distance between workers and robots), but also to facilitate and increase the interconnection across different departments and suppliers located near the plant (or integrated in the plant, as in the case of *Firm 1_MX*). Similarly, the space needed at the factory level has been cited as a crucial aspect slowing down the adoption of new technologies in Indonesia. Here, necessary modifications to the existing factory layout (and the related investment of financial and time resources), were cited as a factor potentially withholding the achievement of higher levels of automation.

To make the process 100 per cent automatic, we need bigger space [to accommodate robots- editor's note] and big investments to replace old machinery that cannot be linked to our digital platform. There are several pieces of equipment that can be digitized, but others are not compatible. [*Key Informant Firm_1_IN*]

Two final remarks related with the conditions of the plant. First, the two Mexican firms both reported the age of the plant as a crucial factor in determining its overall level of automation, since newer plants are more automated and efficient. This is relevant because (i) it reinforces the fact that some constraints are related to pre-existing investments and infrastructure and that these are less likely to exist in brand new plants. In fact, the adoption of automation technologies (e.g., industrial robots, new automated line, etc.) often goes in parallel with the setting up of new plants/facilities; (ii) the challenges in old plants point to retrofitting complexities and how much firms struggle when they are required to retrofit new technologies into existing (old) production lines.

Second, in the case studies interviews, differently from existing literature, the volume of vehicles (i.e., number of components and of motor vehicles) to produce is a major driver (or obstacle in the case of not having enough volume) for automation technologies (Anzolin & Andreoni, 2023; Waldman-Brown, 2020). One of the reasons could be that the countries interviewed – apart from Romania – present high volumes of production – all well above 1 million units per year (Table 1). However, even if not mentioned directly, the two case studies in Mexico made clear that the reason why automation and digitalization did not result in the displacement of workers is associated with the increased demand (thus higher volumes) for vehicles in the US and, consequently, with the need to employ more people that counterbalance the automation of manual operations.

Case study findings: automation technologies' impact on production and employment

Impact on the organisation of production and on global/regional value chains

GVC and headquarters

All firms interviewed for the project are part of regional value chains that are globally integrated. In all cases – but Spain – OEMs interviews were conducted with subsidiaries of firms that have their headquarters in the global North (United States, Japan and Europe). Decisions about automation are very much part of the decision-making process of headquarters. For example, when discussing the obstacles for technology adoptions, the interviews with *Firm 1_MX* revealed that OEMs' budget is not unlimited as they need to compete with other affiliates to obtain new business (i.e., new model or expansion). A key informant in Germany reported that:

'The subsidiaries outside Germany are completely dependent on the headquarter in Germany. If they are introducing key technology those are made in Germany, they don't want to spread the knowledge outside. The European subsidiaries are extremely weak. (...) There is an asymmetry with abroad suppliers, and IGM has requested that new components for electrical vehicles have to be produced in Germany'. [Béla Galgóczi, DEU].

In Indonesia both companies reported that pressure to automate comes from the mother plant in Japan and that it is common for companies to sign off cost reduction agreements with local production facilities, with the result of pushing automation further. Both factories in Indonesia had to adopt a common tracking and maintenance system, which was required at the value chain level and is now fully computerised. Such digitisation process is being expanded to other processes related to warehousing, production, and logistics. Specifically for *Firm 1_IN*, Japanese ownership imposes a strong compliance with digital systems that are already in place in the mother plant, such as the 'E-Kanban' system that automates processes related to ordering, purchasing, monitoring and quality control, while also integrating suppliers to ease procurement and to enhance traceability of goods and services back to the original supplier.

A special, peculiar, case in this scenario is *Firm 1_RO* in Romania, where choices around automation technologies are relatively independent from Renault. Most of the processes are in fact developed internally through a multipolar or domestic strategy (which is also observed at the level of product design and production organisation, see (Pardi, 2019) that turned out to be effective as it makes workers responsible for the choices – and their implementation. Such effectiveness is also related to the fact that 'internal' automation is gradual, and can go hand in hand with people's skills development and new product cycles. For example, in *Firm 1_RO*, the robotization in stamping has been gradual, it started in 2013 and it was completed in 2020, reaching 74 per cent of robotic operations.

'Romania is an engineering hub for the world, we are doing even work for Nissan in Japan. When you go to our engineering centre in Titu, you see engines from all over the world. We use virtual reality for designing and testing vehicles without building physical prototypes. This is a major innovation in terms of automation and digitalization. It has saved us a lot of money, but it has also required a lot of adaptation'. [Firm 1_RO_9]

The automation of the stamping department (loading and downloading presses) involved a significant innovative contribution of the technical team in *Firm 1_RO*, which has been actively involved in solving technical problems.

Indeed, the successive deployment of robots on other presses was done in a shorter amount of time thanks to the learning effect of the initial experience in the stamping department. All complementary parts were acquired by technical suppliers but then internally defined and assembled, according to the specific needs of the plant. Renault was generally supporting automation with the technical support of robots' suppliers, ABB, who, however, was not able or willing to adapt their robots to the specific layout of the presses in *Firm 1_RO*. To overcome these constraints, both programming and internal simulation of robots' specific operation were carried out internally at *Firm 1_RO*. Afterwards, the supplier (ABB) technically confirmed the process and observed results. Once implemented with success, the technical solutions elaborated in *Firm 1_RO* in Romania have been applied in other group plants in Spain and Morocco. The process of adoption of automation technologies has been, therefore, gradual, and progressive. Learning mechanisms and cooperation among different teams have played a fundamental role to ensure an effective implementation of new technologies.

Differently from *Firm 1_RO*, in the case of *Firm 2_RO* the adoption of automated technologies was directed by the parent company which maintained a certain control over the implementation process. Several training courses based on the mother plant Production System (FPS) were provided and, on different occasions, mutual support and cooperation was put in place across the different European units.

A similar case, where there is no top-down approach regarding technologies' adoption is the Spanish supplier *Firm 2_ES*, where innovation projects are not designed in the context of the global European strategy of the parent company. Indeed, according to its management, decisions within the firms strongly depend on the local market context. In this plant, the role of internal innovation and development is extremely important because the technology is defined at the plant level, while products are defined by the customers.

Impact on production organisation

For what concerns the impact of automation technologies in the organisation of production, the overall idea is that there is an upgrading of the production process. Interviews with the Spanish supplier *Firm 1_ES* reported that automation improved the competitiveness of the plant and has not produced substantial changes in the supply chain. Conversely, compared to others in the region, the competitiveness of *Firm 2_ES* is highly increased, but there has also been an impact on the supply chain: due to the internal changes in logistics (due to the use of MES¹⁶ and AGVs), their suppliers are asked and supported to improve their logistics. Two interviewees reported:

'we have noticed a change, especially in the operation of logistics, in the way of changing from a traditional cell of discharge of components, to something more automated.' [*Firm 2_ES_3*]

Firm 2_ES significantly increased the productivity of the plant with the adoption of MES and AGVs. While automation is not new, the implementation of digital technologies has been an essential step to further advance it and to increase productivity.¹⁷ For example, the impact of AGVs on employment was not relevant – they reported that the number of people employed in handling has not been reduced – yet it completely changed the way the logistics department interacts with the production area. This change required the involvement not only of workers in logistics but also of team leaders in the production area, because of their twin role in keeping the working of the technology effective and enhancing the value added by the operators. In *Firm 2_ES*, AGVs make the flow faster and more reliable; interviewees reported that as a result the level of stress of workers is both increasing (due to the reduction in operators' breaks) and decreasing (since AGVs are also supported by MES that records every step of the process avoiding accidents). Although the firm reported a positive experience with AGVs, their use is still a day-

¹⁶ Manufacturing Execution Systems.

¹⁷ For example through digital twin, that allows the company to manage a finer tune of all the waste time in processing (the welding robots or the handling of material through departments), which is controlled more specifically through simulation of different organisational configurations.

by-day process, and they are in the process of designing to introduce digital twin of the current production flow to optimise the plant layout.

In Mexico, platform changes (i.e., the reorganisation of the shopfloor due to new models) drove automation up. In Indonesia, the plant was undergoing a series of transformations to house all steps of the manufacturing process under one roof. The overall goal is to become more efficient and effective to be more adaptable to fluctuations in consumer demand (before issues due to space constraints) such optimization reduced the production costs by 40 per cent; the factory seeks to create a leaner production system that automates non-value adding activities.

Impact on employment and work

Impact on employment and employment composition

As previously stated, the adoption of automation technologies in the automotive sector is a long-term phenomenon that has taken different forms and intensities not only between countries but also along the value chain. As a result, studying automation technologies' impacts on employment, both in terms of quantity and composition, inevitably reflects this decades-long process. However, more recently the implementation of automation processes has increasingly intersected with the adoption of digitisation of processes, whose effects on work cannot be disentangled from the former. This interdependence between automation and digitisation characterises the plants studied in this report, as already discussed in Section 2.

Among the establishments studied during the project, the impact of recent waves of technology adoption on employment is not univocal. In particular, in Spain and Germany, there is no explicit evidence of displacement effects (Krzywdzinski, 2021b), that is a reduction in overall employment, while findings from the case studies in Romania, Mexico and Indonesia point toward a reduction of employment due to the implementation of automation technologies. Moreover, the way the management implemented such a reduction takes different forms. In the case of both OEMs in Romania, the reduction in employment has mainly occurred through retirement incentive plans. Whenever displacement occurs, it is not a generalised phenomenon but as expected it affects only specific occupations. For example, at *Firm 1_RO*, only two main occupations have been affected by displacements: assembly jobs and operators. Retirement plans have been mainly used to manage the reduction of required employment especially for operators. Together with retirement plans which helped not to engage in layoffs, *Firm 1_RO* has managed not to dismiss workers by reallocating them to other posts and set of tasks. A similar reallocation process has been detected in *Firm 1_MX*, where line production technicians have been moved to maintenance tasks:

Obviously when one makes lines more efficient, and not minimizing human resources...[workers-editor's note] need to be relocated. This is the part that I do not like, but I also know that it is a change that must be made; it is to improve, at the end of the day. In some cases, at least in the experience that I have, well, it is not precisely that a person is let go, no, this person is usually relocated. [Maintenance technician, Firm 1_MX]

Relocation of workers adds to a wider reconfiguration of the employment composition as a result of automation and digital upgrade within plants. For example, both in the case of the Spanish and Romanian factories, automation technologies reduced the number of line workers while increasing the number of maintenance jobs, technicians, people in quality control and those employed within the IT department. Yet, the way digital technologies integrate across production departments shapes the need for IT jobs. This difference clearly emerges comparing the case of *Firm 1_RO* and *Firm 2_RO*, where in the former case, the adoption of tablets within the assembly line has been implemented to increase the information flow therefore affecting the content of work of different figures, like team leader supervisors, area managers and defect fixers. In the case of *Firm 2_RO*, there is still use of a more traditional way to provide feedback and to exchange information related to the need for refilling of components.

The gender dimension of employment has undergone a process of relative desegregation. The number of female workers has increased in all visited establishments and especially in production related departments. This shift toward less gendered production processes can be directly attributed to the deployment of automation technologies and more specifically the adoption of new robots able to substitute more physically demanding tasks.

This trend probably reflects more general dynamics towards increasing gender participation and gender equality in employment. Although the desegregation process is common to all case studies, differences in the allocation of female workers into different occupations and departments emerge. To be more specific, in *Firm 1_ES* the gender composition has become more balanced for line workers, while management has only 2 women out of 7 people, and in maintenance there are no women. In *Firm 2_ES*, the overall composition remains highly segregated: operators are mainly female workers, 60 per cent of team leaders and shift leaders are male workers, and maintenance, quality and logistics are only male workers. In the case of *Firm 1_RO*, the share of female workers now reaches 32 per cent and is spread unevenly across departments. For example, very few women are employed in maintenance jobs, while their participation appears to be much higher in painting, although tasks and working conditions are harder compared to the former occupation. The share of women reaches 45 per cent in *Firm 2_RO* where, as in the case of Spain, women enter the production line more frequently, despite still struggling with career progression. Evidence from the two visited plants in Mexico highlight a different pattern. Indeed, in both companies, successful gender inclusive recruitment policies have been in place, especially in the case of *Firm 1_MX* where women are employed not only in the assembly line and other manufacturing stages of production, but also in the quality inspection area. Yet, also in this case, maintenance remains a male dominated production department.

Through our marketing we are looking for people to understand that just because we make cars, it doesn't mean that this work is only for men. In our materials we explain that there are various processes, and that we, as a company, are focused on making safe processes... we do not hire men or women, because any process can be done by both men and women. However, we have carried out campaigns so that more women come to our recruitment process, and I can now tell you that two years ago we were at 24 per cent, and right now we are at 29 per cent... there is no more to add, we don't specify that a certain job has to be done by a man or by a woman, for us it is indifferent, it is more about the capacities, the abilities. [HR manager, Firm 2_MX]

According to these first insights, the effect of automation technologies on labour is more pronounced in terms of the reconfiguration of the bundles of tasks to be performed by workers and therefore the occupational profiles required to perform them. Although some similarities emerge across the cases, regardless of the position of the establishment in the value chain and institutional context, the effect in terms of occupational structure responds to the type of innovation/technological upgrading considered within each specific case study. More precisely, changes occur both at the extensive margins, that is the demand for specific occupational profiles, and at the intensive margins, that is a reconfiguration of tasks within the same occupational profile. From the interviews it emerged that changes along the intensive margins dominate changes along the extensive one.

In terms of the latter, the only appreciable shift reported by the interviews across all fieldwork is the increased need for support workers, in particular maintenance ones. In some cases, respondents highlighted the need to recruit specific profiles like data analytics experts and engineers, as in the case of *Firm 1_RO* and *Firm 1_IN*.

'In my team, data analytics is a "best effort" task. We don't have a specialist for this right now. It is Renault's goal to have at least one data analyst in each team such as ours. Even if we don't have one right now, there are data analysts in France who are able to give us the necessary reports. But in the future, we will have a data analyst dedicated to our plant, who can develop the new kinds of reports. Right now, we have a list of general reports requested by all the plants, but in each plant the local manager wants to have some specific reports and for these kinds of reports it's a bit complicated right now and for this reason we will have a data analyst in our plant'. [Firm 1_RO_8]

Moreover, in many cases respondents report to struggle in finding the adequate people endowed with the required skills.

'There are even some disadvantages since new technologies require very skilled people. We have this problem in Craiova: we cannot find skilled people on the market. Technology is developing faster than the University manages to train people. We have a big problem with this'. [Firm 2_RO_3]

An interesting finding to highlight suggests that occupational reconfiguration does not necessarily involve only direct and internal workforce. This is the case reported by *Firm 2_ES* interviewees, who reported that the introduction of MES had an impact on both operator and maintenance workers directly employed by the company, yet it also affected the system integrator actor, a company external to *Firm 2_ES*. System integrators workers operate as experts in the Industry 4.0 realm and are responsible for the integration of AGV and Manufacturing Execution System (MES), a process that is conducted on the basis of *Firm 2_ES* instructions until the setting is well established and can be managed internally.

Changes in tasks content

One of the main effects following the deployment of automation technology is the reconfiguration of the bundle of tasks to be performed by workers employed along the internal occupational structure. Although these changes go hand in hand with the specific technology and the production stage affected, all the analysed cases share common patterns: the implementation of automation and robotisation technologies reduces the amount of physically demanding tasks performed by workers. Together with a productivity enhancing effect, always pursued as the main objective of technological upgrading, findings from the field studies suggest that safety and health issues also motivate the implementation of automated machines and robots.

There are some work processes that if done manually they are less safe for the workers. Thus, we are changing jobs that are potentially causing health problems. We try to replace them with robots. We can see that [...] people who work in areas that we automate are tired. They work hard, lifting more than a few kilos. There are government regulations that limit the lifting of heavy weights. [Indonesia Key Informant Firm 2_IN]

However, as reported in the case of *Firm 1_ES* not all operations involving physical tasks, even when already embedded in a highly automated process, can be further automated. For example, inside the moulds, some metal, plastic and pieces of fabric are still inserted manually due to the heterogeneity in produced models and because of their tiny dimensions requiring high dexterity not guaranteed by robots. In this case, rather than automating the process, it has been more efficient to introduce a digital device, an optical viewer, to monitor the way these small components are placed in the mould. Overall, optical viewers were introduced to improve visual dexterity while the operation is still performed by human labour.

In the case of *Firm 2_ES*, the adoption of AGV substitutes human and mechanical physical tasks related to the displacement of pieces to be welded from the logistics department to the production line. However, in the studied case, AGVs are not implemented to their full capability. Indeed, and differently than what was seen in the Amazon Italia case study (Cirillo et al., 2022) loading tasks are still mechanical with human direction.

The implementation of digital technologies has an impact on the tasks content as well as on the responsibility of the middle management. More specifically, digital technologies allow the collection of detailed data related to production flows within and among different departments. This information is then used by shift and team leaders as well as middle management to take decisions and act upon, therefore performing different intellectual tasks. Indeed, data collected and simulated organisational configurations require more analytical and problem-solving skills, such as data interpretation and resolution, once errors or dysfunctionalities – with respect to the set goals – are detected. The extent to which intellectual tasks increased or not is hard to establish given the information collected during the visits; although a quantitative assessment of this change cannot be done, a qualitative change can be inferred. In fact, since the information flow increases and covers inputs collected across different departments, workers are required to develop and manage a broader understanding of the production process, not restricted to the specific stage they are allocated to.

This is the case highlighted during the field at *Firm 1_ES*, according to which automation technologies are also essential to guarantee the traceability of the production process from raw materials to the various transformation stages. In *Firm 2_ES* instead, the introduction of AGV has been integrated with the implementation of a MES, the digital system to collect data from operation infrastructure, and production control. Similar findings emerge from

the *Firm 1_RO* case where digitalisation is adopted to reach the goal of continuous control over the quality and efficiency of the production process.

A large number of presses have such digitalized systems that allow to monitor vibration (vibration detectors). Things are controlled remotely, we can see if there's a problem. This was started in 2017 and it began with one press. Now we have around 20. This system holds for stamping for the entire Renault group. [Firm 1_RO_2]

The inspection is done automatically, and the camera is able to recognize problems. This technical solution solved problems with customers. The important thing is that if there are mistakes, we find them in the plant and they don't go out. We bought a standard camera that we did not develop; we are not capable of that. [Firm 2_RO_5]

From the reported examples, we can infer an increase in intellectual tasks and more specifically of both technical literacy, i.e., the ability to read information from technical reports, forms, and tasks related to information gathering and evaluation.

Finally, it is important to note that the increase in intellectual tasks do not concern operators but only middle management, team leaders and maintenance workers. This finding is shared across the Spanish establishments of *Firm 1_ES* and *Firm 2_ES* but it also applies to the case of the *Firm 1_RO* plant in Romania, that is whenever both automation and digitisation are deployed. On the contrary, in *Firm 2_RO* the use of digital devices and tablets is less developed within production departments.

The asymmetric increase of intellectual tasks across occupations implies that the impact of automation (together with digitisation) produces an upskilling of some profiles, namely middle management, team leader and maintenance workers. Conversely, the same process *deskills* operator, therefore concentrating not only intellectual tasks but also decision making and control at the top of the internal hierarchical structure.

Changes in work organisation

In what follows we will focus on the organisational practices emerging as a result of the adoption of automation technologies within different production stages. Organisational practices embrace several dimensions related to the way workers perform their production tasks, the extent to which they enjoy forms of autonomy and discretion, the degree of repetitiveness of their tasks and the requirement to follow detailed instructions and/or organisational routines. Finally, we will discuss whether the deployment of automation has an impact on job mobility and rotation within the plant and its rationale. Again, the reshaping of work organisation within the plant and production stages, following the introduction of automation and digitisation, responds to the main aim of increasing productivity.

Productivity, we need to increase productivity, we need to look at every single item (not necessarily robots, cobots or things like this), even the smallest things, we have to identify opportunities; even if an operator travel takes 7 steps to a shelf and he can take 5 or 6 we need to address this; automation is good for productivity, stability, quality. (...) Efficiency needs to be considered continuously. [Firm 2_RO_7]

How can automation and digitalization increase productivity and efficiency in our production team, that's our goal. [Key Informant Firm 1_IN]

The trade-off was that to increase production capacity, the robots took most of the jobs that were done by people... The workload of the people got reduced, but the quantity of the cycles done per hour increased and that allowed for more productivity. [Stamping manager, Firm 2_MX]

Productivity goals are mainly achieved by decreasing takt time (the amount of time between the completion of one unit and the beginning of the next), by increasing saturation time (the target speed or rate of work), and more generally the intensity of work. This is widely reported by interviewees among all case studies. In the case of *Firm 2_ES* in Spain, it has been stressed that AGVs make the flow faster and more reliable but reduce operators' breaks and this increases their stress. The saturation level is not necessarily set at a given rate; indeed, it ranges from 50

per cent to 90 per cent depending on the welding cell. Also, in the case of *Firm 2_RO* saturation time reaches 80 per cent (with an upper bound of theoretical rate of 90 per cent). Similar considerations emerge discussing the introduction of AGV in the *Firm 1_RO* plant and as general outcome in the case of the Mexican case:

In general assembly, there was an improvement in terms of flow, with fewer delays due to AGVs that now supply the line with parts and components. Due to these vehicles, the supply of parts to the workers became streamlined, with reduced delays and a continuous work flow. Overall, positive things that people had to get used to. ... before the AGVs, because of the delays, workers had some dead seconds where nothing was happening. Now this has been eliminated and workers are forced to work all the time, without these small breaks. [Firm 1_RO_10]

"[...]The workload of the people got reduced, but the quantity of the cycles done per hour increased and that allowed us more productivity". [Stamping manager, Firm 1_MX]

Higher saturation time and therefore working intensity seem to be achieved through increasing standardisation of tasks and operations especially repetitive ones that are not yet automated. Indeed, in most of the analysed cases, the repetitive character of given tasks in different production stages is meant to be reduced thanks to the deployment of automation technologies. Repetitive tasks especially within structured environments are considered easier to be replaced by automated machines

The body shop and the engine shop are most suitable for automation; you have repetitive processes, accurate parts, precise and stable dimensions, stable quality, so automation is much easier to do than in Trim & Final. [Firm 2_RO]

The automation of relatively repetitive tasks is considered by interviewees from the management as an improvement in working conditions for workers.

The routine on the assembly line it's astonishing. You are basically a robot, without knowing it. You have to know the operation and all day you do only that. Imagine doing that for 30 years. I don't imagine myself doing that and I don't want to imagine people doing that. That's why we have the technology. [Firm 1_RO_4]

Reducing repetitive tasks was a main driver of automation after stamping. In the assembly line in the vehicle plant, we still have a low degree of automation. We are now focusing on what we could do in vehicle assembly. People still work like mini-robots there. [Firm 1_RO_9]

The possibility to automate repetitive tasks is also functional to increase the degree of standardisation of the remaining tasks performed by human labour. This is achieved by data collection and analysis spurring from the digital technologies embedded or complementing automated machines. As reported by an interviewee at *Firm 1_RO* and to some extent at *Firm 2_RO*, the standardisation of operations is pivotal to increase productivity since it allows to increase the pace of work:

We tried to increase production capacity. To be efficient you need to produce at max capacity. To do that you have to reduce cycle time: from one car every 60 seconds to every 54 seconds. For this, you have to split the operations in smaller and smaller pieces, which means one operator has to do fewer and fewer operations. [Firm 2_RO_9]

As it might be expected, the standardisation of operations performed by workers has a negative impact on their level of autonomy and discretion (Bisello et al. 2021). At the same time, the adoption of digital technologies to collect and analyse information on production flows also increases the possibility to monitor individual productivity, strengthening managerial power through indirect forms of control (Fana and Villani, 2023).

Digital recordings of machine TPM [Total Productive Maintenance] facilitates better coordination across departments because "you can see what they have done, what they have not done. [Firm 2_ES_7].

The possibility to track individual and team productivity and to apply forms of reward/punishment has been addressed only in the case of *Firm 1_ES* where according to the interviewees, the pace of work is not necessarily high, but workers receive bonuses related to their level of productivity. Also in the Indonesian case studies, a sanction mechanism applies to workers when individual performance does not meet established targets. More specifically, workers underperforming undergo the termination of their permanent contract and are then hired as contractors with major worsening of their working time, wages as well as social security coverage. It is interesting to note that these mechanisms mostly affect low-skill workers therefore acting as a 'disequalising' channel across the workforce.

Within the realm of work organisation special attention should be paid to the decision-making process and how the possibility to take decisions and act upon them is shared within the occupational hierarchy. As in the rest of the report, what matters here is to what extent the adoption of new technologies has an impact on how decisions are taken within the plant and/or stages of production. For example, in the case of *Firm 2_ES*, decision making tasks strengthen in the case of middle management on a daily/shift basis involving team, maintenance and quality managers as well as those of the logistics department.

the more important point is the people use the data to make decisions during production time and then we are working right in training people with role games to try make understand all people what is each number. This is very important for us because is our challenge, because we have the technology, but we need the people make decisions without "Juan Carlos please tell me what means this or we don't want to do this". We are working in the second level, because first of all, we worked with managers and second level was shift leaders and team leaders. And we are working right now with the shift leaders and team leaders because they must interpret data. [Firm 2_ES_1]

Operators are considered unqualified to have any responsibility to take decisions when key performance indicators are below the target.

In the case of Indonesia, there has been a process of centralisation to top level management where information flows accrue was identified as linked to digitalisation:

With digitalization, all data and problems can be channelled directly up to the top-level management, regardless of where they are. When there are abnormalities or unsolvable problems, the related parties can be immediately informed. [Key Informant Firm 1_IN]

Moreover, even the role of middle and top management in decision-making appears to be potentially impacted and automated by further technological upgrades:

The concept is to join different technologies, artificial intelligence plus Internet for things plus blockchain plus digital twin, in one welding cell, to learn how we can combine these technologies and then how these technologies can collaborate to make decisions automatically without people. [Firm 2_ES_1]

Apart from these few highlights, the respondents did not focus much on this topic during the interviews.

Job rotation

An important feature of work reorganisation following the introduction of new technologies is the adoption of job rotation schemes, although the rationale behind their introduction differs across the analysed cases.

Job rotation of workers is important for both *Firm 2_MX* and *Firm 1_MX*. In *Firm 2_MX*, job rotation is implemented as a mechanism to improve individual productivity and skills which could positively affect job mobility to higher positions.

we assume that if you are doing your job well in this area, you can also do it well in another... because we know that with the tools we have within the company, it is nothing more than problem solving (HR manager, Firm 2_MX).

I came to Firm 2_MX 19 years ago working as an engineer in the maintenance area and from there I have rotated through various functions of the company, having responsibilities not only for maintenance, but also for the environment, safety, hygiene, cabin production, quality control. I am currently in the assembly area as a group manager. (Group manager, Firm 2_MX).

Similar considerations apply to Firm 1_RO but only for specific positions. Indeed, in this case job rotation is particularly important for defect fixer and maintenance workers, where rotation applies to teams rather than individuals.

In Firm 1_ES, workers accept and even ask for rotating to a different part of different operations as a way to gain experience and skills in other departments. Besides training and upgrading, job rotation can be used to mitigate mental stress and physical health issues related to high workloads. This is the case reported by respondents in Firm 2_ES and trade unions in Firm 2_RO.

for example, the operator who is working on the welding [roll forming] press is very saturated and stressed, because he has to achieve the cycle time, having to do a lot of manual operations to reach the cycle time [Firm 2_ES_3]

Periodically, we rotate the operators to jobs with different movements, more comfortable jobs, or based on medical restrictions. If you have an injury and you can only work on the first shift and you are not allowed to carry parts heavier than 5 kilos, we need to accommodate you and rotation is a solution. Team leaders have a versatility matrix that they update periodically (once per month or every time when they train an operator). [Firm 2_RO_2]

However, job rotation is not necessarily conceived as a productivity enhancing mechanism. Indeed, according to the trade union, job rotation is hard and even resisted by line operators who feel uncomfortable in reaching a high level of performance in different production stages as reported both for Firm 1_RO and Firm 2_RO:

Due to the very high workloads, people have become so specialised, so accustomed to specific jobs, that it is very difficult for someone else to come in that job and have the same level of performance within a reasonable amount of time. [Firm 1_RO_10]

Training, upskilling

As it can be expected, training is an essential process in the face of technological upgrade within plants. All visited establishments provide several on the job training programs to their workers aimed at internally developing the required skills and capabilities. Training is provided internally or externally depending on the establishment. Moreover, the programs and intensity of the training differ among occupational profiles depending on the exposure to the implementation of new technologies.

For example, Firm 2_RO specific training is provided by the parent company

Training for maintenance people: 1) based on the equipment, you can buy vendor training; 2) on the job training: to know how to debug a line, to diagnose a fault, for these you need to see the line, to see the robot on the line, that is more difficult. You need robot training, PLC training, IT skills, so you need to put together 5-6 types of skills in order to understand what the problem, find the solution and restart things [Firm 2_RO_2]

in our experience maintenance people need 8 to 12 months to know exactly how is running the line, the factory shifts leaders and team leaders, two years. [Firm 2_ES_1]

In Firm 1_ES, training addressed to the maintenance team is provided externally by the supplier of the technology although not always:

The training is given by the supplier of the machine. ... the external provider sometimes does not give you training, depending on the processes. And I [he is the maintenance manager, editor's note]

personally don't need it because you know how it works. What you do is explain it to the rest of the team [Firm 1_ES_6]

In other cases, like Firm 1_RO, training for the maintenance team is provided externally by international expert organisations like Bosh, Siemens, UiPath, which are also technology suppliers, and other Romanian providers. External provision may go beyond the maintenance team as highlighted in the Indonesian case where training is foreseen only for permanent workers with at least three years of tenure:

We still rely on workers who have technical competencies, even though most are high school graduates, they may have some expertise, for example operating computers and so on. We give them some training when we buy and install robots, it comes with a training package from the machine manufacturer. [Key Informant Firm 1_IN]

Given the upgrade in analytic and problem solving tasks related to the introduction of digital technologies, special attention is also devoted to team and shift leaders as well as middle management in charge of interpreting collected data flows.

it is important to train people so that they can get the best out of these technologies. If you don't, you lose a lot of their capacity. Especially in the plant and in the lines, because in the lines is where they impact the most and that is why we are very focused on the middle management of production, they are for us a priority. [Firm 2_ES_8]

We introduced the technology so far but we are still training our shift leaders to make the interpretation of the data, because introducing the technology is relatively faster, but, implement, half year, running...but the more important point is the people use the data to make decisions during production time and then we are working right in training people with role games to try make understand all people what is each number. [Firm 2_ES_1]

Finally, also blue collars and operators are involved although to a very lesser extent in training programs. More precarious staff, like university students hired to cope with peaks in production undergo only limited training programs. Indeed, although they are required to do the same job as permanent workers in the line, they are entitled only to three days of training against 15 days for permanent staff.

Putting together the main evidence from the last two sections, it emerges that operators get only very short and basic training related to new technologies, while training related to the information collected and their potential use within production is restricted to middle management and few professionals at the top of the occupational hierarchy. At the same time, increases in intellectual and problem-solving tasks only concern the latter. Therefore, it can be argued that the introduction of new automation and digitisation technologies tends to reinforce hierarchical differentiations in terms of power and command over the production and labour process.

Industrial relations and trade union involvement

Across all analysed cases, the unionisation rate is quite high, ranging from 40 to 90 per cent, and, as expected, mainly covers operators and in some cases also maintenance, logistic and quality workers. Managers are in general not unionised or belong to a different trade union than workers. In one of the Romanian cases, it was reported that managers are forbidden by the top to join a union.

However, in the cases analysed trade unions play a traditional bargaining role and are not directly involved in the implementation of new technologies although with some differences among the cases. More specifically, trade unions are mainly concerned with wage setting and collective agreements as well as overall working conditions. It is interesting to highlight that beside collectively agreed wages, during the interviews it emerged that in one case, a rewarding scheme based on individual performance is in place in agreement with the trade union.

They are called 'technical units per hour', and there is a little table that, depending on how many are produced, the operator gets a bonus at the end of the month. [Firm 1_ES_3]

In terms of working conditions, trade unions' activity mainly involves issues related to the pace of work, job content and health and safety. Yet, it is as if they are endowed with a passive role that is to monitor whether agreed standards are not broken unilaterally by the employer.

Trade union consultation on the line's speed? No. If the headcount is aligned with capacity and cycle time, the union cannot complain. The union has this information. They check so that the speed is not changed without them knowing. The union should make sure that the workload for people is not larger than what we agreed and that the speed of the line is not increased arbitrarily. [Firm 2_RO_9].

Health and safety together with the potential of dismissals are the main concerns related to the introduction of new technologies, and in particular automation. However, since in most of the cases dismissals are not an issue, industrial relations are not tense and workers representatives' main perception is not negative

And the impact? Well, since we have been related to Toyota, we have not had anything alarming, nothing in which the technological impact affects the workforce and create cuts for this reason. I think it has been a balanced adjustment between the entry of new technologies and the hiring of labour". [Union representative, Firm 1_MX]

Moreover, as reported during the visit at one of the Spanish plants, trade unions are not concerned with a potential increase in workers monitoring and surveillance due to the introduction of new digital technologies.

Overall, we did not find a single case in which trade unions are involved in the decision-making process of technological upgrading within the plant nor on several and important aspects related to its impact besides labour displacement, like work organisation and the casualisation of work characterised by temporary hirings for peak loads and week-end shifts.

Conclusion

Automation has often been presented as a relentless and unavoidable phenomenon, threatening to revolutionise factories and replace workers. In this study, we have explored the current status and extent of automation in the automotive sector across different countries. The automotive sector epitomises advances in automating the manufacturing industry owing to its peculiar combination of high-volume production and highvalue added processes, which spurs the automation of productive processes. This study confirms and extends an existing body of literature on automation in the automotive sector. The industry is automating, although at a slow pace and with several conditions that must be met before implementing automation technologies; without such conditions – which are technical, economic, and managerial – automating is not appealing, despite its promise of high productivity. In this report we examined and presented the findings coming from interviews with workers, managers, unionists and technologists in five different countries. These are primary data that focused on the level (state of the art) of automation technologies, its main bottlenecks and drivers, as well as its impact on work and the reorganisation of tasks and industrial relations.

First, in terms of drivers and bottlenecks, across different countries, our study confirms that first and foremost financial considerations and budgetary are which shape the opportunity to adopt automation technologies. While increases in productivity, quality of the products, and reduction of labour costs provide a great economic incentive for the adoption of new technologies, usually this entails an expensive, capital-intensive project that needs to have a good 'business case'. At the plant level, budgetary considerations are important both for final assemblers (competing with other plants of the same group) and for suppliers (that often do not have the financial margin for a big investment) as they strongly determine the final decision on whether to automate or not. Within the boundaries of a positive economic impact (i.e., a 'business case'), several other factors influence management in the choice on whether to automate or not. Improvements in the safety and ergonomics of the process, and the possibility to complete automation of certain tasks, have positive impacts on the workers' health and well-being.

These improvements are generally well received among workers and unions, but at the same time they can only be adopted in the presence of the right skills and the managements mindset on training. Automation technologies can only be introduced with success if the workforce possess the right set of skills and capabilities and the management is willing to invest in training programs for the deployment and the continuous improvement and deeper integration of these technologies in the productive process.

Second, with reference to the impact of automation technologies on employment, the case studies reveal few concerns. However, the evidence emerging from the case studies still suggests some cases of workers redundancy, an aspect that is “solved” - in most of the cases - through retirement plans (often anticipated) that are not followed by new hirings. On the gender composition of workforce, the findings highlighted a process of gender rebalancing partly thanks to the reduction of physically heavy and repetitive tasks although the sector remains highly male-dominated.

Although the deployment of automation (and digitisation) technologies does not imply a harsh employment displacement, it brings relevant changes in terms of employment composition and working conditions. On the former aspect, the reduction in employment does not occur simultaneously to the introduction of new automation technologies, but over time and indirectly through retirement plans and reduction in new hirings. In some cases, like the Mexican one, reduction in employment due to automation has been mediated by the increase in demand leading to the expansion of production. On the latter aspect, maintenance workers appear to become the pivotal profile together with engineers and data analytic professionals while line operators are relatively less relevant. Automation has reduced the execution of heavy and repetitive tasks, which increases job quality and improves working conditions, while it increased work intensity especially for operators. Relatedly, the deployment of digital technologies implies some deskilling of operators due to the concentration of intellectual tasks at the top and middle management level, but also a reduction in workers autonomy and the possibility to introduce mechanisms of discipline spurring from the monitoring of individual performance. Lastly, although automation reduces physical health and safety risks, it can increase stress and mental burden in several occupational profiles.

The relocation of workers into new occupations and tasks goes hand in hand with training to reskill them. However, line operators are less involved in training as well as temporary workers, suggesting that establishments invest less on these people. It is worth recalling from the field interviews that training programs could be organised internally or managed by the company headquarters as well as external providers, i.e., suppliers of the technology. Forms of deskilling involving line operators emerge together with concentration of decision-making power at the mid-management, teams and shift leaders level.

Evidence from the case studies also highlight that the information flow spurring from the deployment of digital technology is way less used than its potential. This applies both to the technical production stages and to work organisation. Indeed, forms of algorithmic management and digital control are not yet deployed. As emerged from the interviews, analysing data is firstly an investment in terms of infrastructure and labour. At the same time, a strategy on how to manage requires an upgrade also in terms of management strategies and culture.

Finally, the limitations of the study should be clarified and should be considered when drawing general implications. First, this cross-country study is characterised by a high degree of heterogeneity that depends, among other things, from three main aspects. First, institutional and geopolitical factors, such as the minimum wage legislation in Indonesia, the NAFTA trade agreement in Mexico, and the European integration process that have been impacting, although in different ways, both Romania and Germany. Yet, findings cannot be generalised neither at the country nor at the sectoral level. Second, these countries participate in the international division of labour and production,

yet they are positioned at different levels of the automotive value chain. For example, Germany possesses not only high manufacturing capabilities but also engineering design capabilities and complementary capital goods, which are all elements that contribute to a high value adding process. A different case is Spain, a country that lies at the periphery of Europe in terms of the division of labour in the automotive sector with an increasing specialisation in the final assembly segment. Third, and related to the second aspect, the automotive sector in each country – for the exact reason that it is an industry that often lies at the core of the industrialisation process – reflects where a country is in terms of industrialisation and productive capabilities development. On this last point it is interesting to note how interviewees in Germany reported that the full potential of automation has been reached in terms of its combination between opportunities and feasibility, while in Indonesia interviewees reported that factories are looking for more ways to explore/deepen automation. This has implications both in terms of employment and of (the division of) production: on the one hand, employment may still be subjected to changes and redundancy phenomena in countries where automation has not reached its potential; on the other hand, the scope for automation in emerging economies means that there is further space to increase value adding processes and value capturing in the international division of production.

Despite such limitations, the insight from primary data suggests important policy implications on two points. First, the deployment of automation technologies in the automotive sector and its impact on employment and working conditions needs to be evaluated jointly with the most recent technological advancements, like digitisation and potentially algorithmic management processes. Although from the policy standpoint most of the attention is devoted to potential displacement of workers, other relevant effects are mostly related to work organisation, working conditions and the way they asymmetrically change across occupations needs to be addressed. Second, the design and implementation of policies needs to strictly evaluate, possibly through indepth mapping of capabilities at the firm and country levels, what are the spaces and opportunities for upgrade and development, bearing in mind that windows of opportunities created by automation technologies require high standards in terms of infrastructure, skills, and organisational and productive capabilities.

A final word on the future of this stream of research both at the academic and policy making levels. This subject is complex and multifaceted, and studies that adopt a deductive method are highly instructive to understand the dynamics in a recent phenomenon. The research could be improved and enriched by studies that map/study other segments of the automotive value chain, while also considering the transition and changes related to electric vehicles and mobility.

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3. Automation and employment in the apparel and footwear industry: Findings from case studies in Germany, Indonesia, Mexico, Romania and Spain¹⁸

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The impacts of new industrial technologies – including robotics, advanced material handling tools, digital sensors, vision systems, and many others – on work and employment have been the subject of much debate, yet not much is known about what is happening at the factory level. The future of work across industries depends not only on the availability of technologies but on several other considerations including relative capital and labour costs, infrastructure, labour and skills availability, the broader institutional setting where production takes place, and how these concerns shape decision making on many levels and by many actors (such as firms, workers, and governments) (Bárcia de Mattos et al. 2022).

This paper is the outcome of a project aimed at improving our understanding of how technological upgrading and automation of production processes in apparel and footwear manufacturing interact with local social structures, cultural and institutional systems, and work organization to impact women's and men's employment. Potential impacts relate to multiple dimensions, including the number of jobs in factories (and the industry), the occupational composition of the workforce, the task makeup of occupations, conditions of work and employment, as well as social and organizational aspects of production including workers' autonomy and dynamics of control, and industrial relations.

The apparel and footwear industries have historically been instrumental in industrialization processes providing an entry point into global supply chains and have been an important source of employment opportunities, particularly for women. In 2019, before the onset of the global COVID-19 pandemic, it was estimated that the textile and apparel industries, combined, engaged 91 million workers (ILO 2020), and that in apparel specifically, four in five workers were women (ILO 2019).

Despite some advances in recent years, new and old production systems coexist in apparel and footwear manufacturing (Altenburg et al. 2020; Bárcia de Mattos et al. 2021; Kucera and Bárcia de Mattos 2020; Bárcia de Mattos et al. 2022). There are more advanced technologies at the ends of the supply chain, particularly textiles at one end and logistics and retail at the other, relative to apparel and footwear manufacturing per se. Within manufacturing, material handling remains a key challenge due to the pliability of fabrics (each fabric with its own characteristics), combined with constantly changing apparel and footwear products made in various sizes. While the cutting of fabric has been automated to a considerable extent, sewing largely continues to require that workers manipulate fabric through sewing machines (Kucera 2020). Against this background, the extent to which technological upgrading, particularly automation and digitization, transform the industry, will have important implications for workers. A central question is whether increases in the capital intensity of production alongside increases in productivity in the sector would be associated with the defeminization of workforce.

Some literature suggests that automation has asymmetric impacts on the employment of women and men, providing empirical evidence that manufacturing industries characterized by a feminized workforce frequently experience a contraction in the proportion of women workers with increases in capital intensity (Tejani and Milberg 2016; Tejani and Kucera 2021; Seguino and Braunstein 2018; Caraway 2006; Kucera and Tejani 2014). Tejani and Kucera (2021) have found negative impacts of labour productivity increases on women's employment within the apparel and footwear industry. Although there is limited evidence regarding the forces behind these outcomes, some hypotheses are proposed in literature. These include, for instance, the lesser importance of women's labour

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in more capital-intensive production; cultural norms which attribute to men the role of breadwinners and delegate women to the role of secondary workers; and the skills required for new industrial jobs, relative to the supposed differences in skills of women and men (Tejani and Kucera 2021). However, th

ese hypotheses are not often directly investigated, partly due to the quantitative nature of much of literature, which relies on aggregate and sectoral data.

The research presented in this paper aims at contributing to a better understanding of the complex employment impacts of technological upgrading, particularly its gender dimensions. This paper presents findings from 14 case studies of factories which have made considerable efforts towards technological upgrading and automation. Located in Germany, Indonesia, Mexico, Romania, and Spain, the factories produce knitted and non-knitted apparel – including for instance knitted socks, bags, jeans, and uniforms – and a range of footwear products, such as sports shoes and sandals, for own-brands and international brands, both for the domestic and export markets.

The next section introduces the research methodology and a brief profile of the establishments selected for case study. Next, case study findings are presented along three dimensions, namely: production processes and the technologies currently implemented in the establishments studied; drivers and obstacles to technological upgrading and automation; and impacts on the quantity and quality of employment. A discussion on cross-country cross-factory insights follows, and the paper closes with conclusions.

Methodology

This research investigates automation technologies currently used in the apparel and footwear industry, recent trends in technological upgrading, and their impacts on the quantity and quality of employment for women and men. To this end, the research team identified a sample of between two and four manufacturing establishments in each of the five project countries for conducting in-depth case studies. These establishments have taken significant steps in technological upgrading and represent a diverse mix of apparel and footwear manufacturers, in terms of product type, factory size (in terms of number of workers) and their position in the supply chain.

The factory case studies are based on 125 semi-structured interviews conducted between June and December 2022. Interviewees were selected by the factories, based on pre-defined profiles, including managers, technology specialists, production workers, and workers' representatives. Each case study encompassed between 5 and 15 interviews. Interviews were conducted face-to-face, accompanied by site visits whenever possible and following guidelines tailored to each respondent profile across all countries. Discussion topics included technological upgrading and automation, technology and workers, working conditions, training and career prospects, industrial relations and dialogue, and general prospects for the future. In all cases, the gender composition of interviewees was carefully managed to ensure women were represented among production workers, and gender dimensions were included across all topics.¹⁹

Some caveats must be considered in the interpretation of research findings. First, although interviewees were assured that interview discussions would remain confidential, the fact that workers were selected by management and interviews carried out at the workplace may have affected answers. In addition, the small sample size and factory selection strategy prevent us from generalizing results to the global apparel and footwear industries. Nevertheless, that the selected establishments are located in countries across the world, with diverse social and economic profiles, and that these establishments encompass large and small factories at the forefront of technological upgrading and automation, suggest this research project makes a significant contribution to understanding drivers and barriers behind the observable trends in technological upgrading and its employment impacts, including gender dimensions, in the apparel and footwear industries. It is also worth noting that despite being conceptualized before the COVID-19 global pandemic, this research was conducted during the crisis, which severely impacted economies and businesses across the globe. As a result, we also addressed the impacts of COVID-

¹⁹ Fieldwork guidelines including the full set of questions are available from on request.

19 on establishments' technology adoption and employment. Overall, interviews suggest that COVID-19 did not affect decisions related to automation at the factories studied, though businesses were disrupted and employment impacted, even if temporarily.

Table 2. Profile of the establishments selected for case studies

	Country	Type of product	Business profile	Number of employees	Number of interviews	Role of respondents
GerApp1	Germany	Apparel	This establishment produces bags for its own brand since the early 1990s.	20 (50% women)	9	1 manager (men); 3 technology specialists (2 men and 1 woman); 5 production workers (4 women and 1 man).
GerApp2	Germany	Apparel	Recently founded, this factory manufacturers jeans for its own brand.	100 (40% women)	9	4 managers (3 men and 1 woman); 5 production workers (4 women and 1 man).
IndApp1	Indonesia	Apparel	This factory produces women's underwear, primarily bras, for international brands, predominantly for the US and European markets. It is part of a Burmese-owned manufacturing group and a partner of the Better Work programme*.	4,000 (90% women)	10	3 managers (2 men and 1 woman); 1 technology specialist (man); 1 workers' representative (man); 5 production workers (3 women and 2 men).
IndApp2	Indonesia	Apparel	This establishment manufacturers sportswear and outdoor apparel for international brands. Korean-owned, the establishment produces exclusively for exports, markedly the US market, and is a partner of the Better Work programme*.	1,000 (90% women)	8	1 manager (man); 1 technology specialist (man); 1 workers' representative (man); 5 production workers (3 women and 2 men).
IndFtwr1	Indonesia	Footwear	The establishment produces own-brand slippers and sandals for the domestic market, serving the lower- and middle-class segments. It is one of several factories owned by this Indonesian business.	900	11	3 managers (2 men and 1 woman); 2 technology specialists (men); 6 production workers (3 women and 3 men).
IndFtwr2	Indonesia	Footwear	This factory manufacturers sports shoes for an international brand for exports mainly to the US and European markets, as well as Japan and China. It is part of a company established by Korean entrepreneurs and a partner of the Better Work programme*.	5,200 (67% women)	9	3 managers (2 men and 1 woman); 1 workers' representative (man); 5 production workers (3 men and 2 women).
MexApp1	Mexico	Apparel	The site includes two interconnected factories which are part of a fully Mexican-owned conglomerate manufacturing and selling industrial uniforms and work clothes, as well as suits and custom-made suits for own brands and international brands, mostly for the domestic market.	1,400 (60% women)	6	2 managers (men); 4 production workers (3 women and 1 man).
MexApp2	Mexico	Apparel	This case study includes two plants working in close collaboration cutting and assembling garments, respectively. The establishments are part of a Mexican-owned, vertically integrated, group. It produces underwear for its own brands as well as international brands, largely for domestic consumption.	1,300 (70% women)	8	2 managers (men); 1 engineer (woman); 5 production workers (3 women and 2 men), incl. a workers' representative (woman).
MexFtwr1	Mexico	Footwear	The factory is part of a large Mexican footwear group specialized in the production of high-end cowboy boots, fine footwear and leather goods using exotic animal leather, with operations in Mexico and	1,400 (40% women)	15	8 managers (6 men and 2 women); 7 production workers (4 women and 3 men).

			abroad. This site encompasses two interconnected factories producing mostly for the group's own brands and the Mexican market.			
MexFtwr2	Mexico	Footwear	Large family-owned footwear business employing over 5,000 workers (40 per cent of which are women), and manufacturing 70-75,000 pairs of shoes daily. The firm produces for its own brands, mainly for the domestic market, as well as for international brands. The study was conducted at one plant and headquarters, and part of production for this plant is outsourced to external manufacturing units.	1,700 (n/a)	10	4 managers (men); 2 engineers (men); 3 production workers (2 women and 1 man); 1 business chamber representative (man).
RomApp	Romania	Apparel	Founded less than ten years ago, this establishment produces socks for the national and export markets, largely EU and US.	13 (38% women)	9	1 manager (man); 1 supervisor (man); 7 production workers (4 women and 3 men).
RomFtwr	Romania	Footwear	This factory manufacturers vulcanized shoes for over 35 international brands. Export markets include Japan, USA, Italy, Spain, France, Mexico, South Korea, UK, Hungary, and others.	126 (79% women)	7	1 supervisor (woman); 7 production workers (6 women and 1 man), incl. a workers' representative (woman).
SpaApp	Spain	Apparel	A Spanish sock manufacturer founded in the early 1990s. They produce high-end sports and technical socks available in national and international markets.	45 (53% women)	5	1 manager (man); 2 supervisors (1 woman and 1 man); 2 production workers (1 woman and 1 man).
SpaFtwr	Spain	Footwear	A footwear producer since the 1960s, this establishment manufacturers children's footwear for their own brand and international brands.	40 (37% women)	9	2 managers (men); 3 supervisors (men); 4 production workers (2 women and 2 men).

Notes: *The Better Work programme is a partnership between the International Labour Organization and the International Finance Corporation. Participating firms have made a commitment to decent working conditions and to being regularly evaluated on multiple dimensions of compliance, including with respect to gender equality.

Source: Authors, based on information shared by informants.

Case studies: Interview findings

Information collected through the interviews is discussed along three dimensions (i) production processes and automation technologies currently implemented in the selected establishments; (ii) drivers and barriers to technological upgrading and automation; and (iii) impacts on employment, both quantity and quality, including gender dimensions.

Production processes and current use of automation technologies in selected establishments

Production across all factories studied relies on a mix of machinery, ranging from mechanical equipment operated manually, to semi-automated and automated machinery, as well as digital processes. Generally, there is more automation in product design, spreading and cutting, and less automation in sewing, finishing, quality control and packaging. Product type is also correlated with automation, with more automation in the production of knitted apparel (e.g. socks in Romania and Spain) than in non-knitted apparel (e.g. clothing in Mexico and Indonesia). Likewise, vulcanized shoe production lends itself more readily to automation than the manufacture of leather footwear.

In **Mexico**, at MexApp1, pattern design and development are carried out with digital systems. Rolls of plain fabric are spread automatically, and cutting is done with modern, automated machines with steel-blades. However, checkered and plaited fabrics, and combed textiles, which are more delicate, are spread and cut manually. Afterwards, a worker places the cut fabric and interlining on the fusion machines, which are all automated. Sewing comprises a long list of sub-operations. For example, in the case of suits, it includes selection of front and back, sleeves, pockets, necks and trims to be assembled in a carefully designed step-by-step order, to produce the final garment rid of extra threads and rims, with its final touches and revisions to then be ironed. These operations use very different machines, some of them are automated and carry out various tasks. Others are semi-automated machines with electronic screens attached, and there are also manually operated tools and equipment, such as for necks and some trims which require very fine details that the automated machines cannot reproduce. At MexApp2, digital systems are used to create patterns, and assembly is simulated and planned using a 3D system. Rolls of fabric are first laid out by hand, and then cut automatically before being sent to the assembly plant. There, the cut pieces are sewn using a wide variety of equipment: mechanic with no electronic panel (e.g. for waist tying operations), semi-automatic with a programmable panel, and autonomous (e.g. for embroidery). Finally, the undergarment is sent to quality control.

At MexFtwr1, leather is first prepared for cutting, after which the pieces are embroidered and engraved. The components are then backstitched and assembled. Finally, accessories (avios) are placed, and products are finished and adorned. Automated and semi-automated machines are used for sewing, backstitching²⁰ and embroidery. Most of the cutting is done manually, due to irregularities in exotic leather, but some is done using automated lasers. Moreover, design is done digitally, and the company uses enterprise resource planning (ERP) software for management and product traceability. This is similar to what happens at MexFtwr2, fabrics are layered on special tables and components are drawn to minimize waste. Following, layered fabrics are cut (manually using templates, or with semi- or automated machinery) and leather components are mounted and tamed. Next, pieces are embroidered, and interlining is added with semi-automated equipment. Backstitch operations are carried out with semi-automatic machines that have digital attachments like control panels and touch screens. Insole preparation follows (including attaching it to the shoe upper) using semi-automated machines, robots and direct injection. Finally, the footwear is fully assembled, dried, ornamented, polished, and packaged, before it is transported to the warehouse.

²⁰ Backstitching provides an example of the differences between automated and semi-automated equipment. Automated machines cut the thread and generate the seam for backstitching, others do the edging to prepare the backstitch. Semi-automated machines – i.e. sewing machines with digital touch screens – count stitches, cut thread and tie it.

In **Indonesia**, the production activities on the factory floor of the two apparel factories follows a similar sequence. First, rolls of fabric are delivered for spreading followed by fabric cutting and then sewing. Key differences in production activities between the factories is that IndAppr1 has fabric moulding operations for shaping bra cups, hooking operations for sewing metal hook and eye closures onto small patches of semi-rigid fabric, creating adjustable fastener units, and strapping operations for stretching straps prior to their being sewn to these fastener units. In mid-2022, the factory was implementing automatic spreading, cutting was automated, and strapping and hooking were done entirely by semi-automated equipment. In the first two operations, workers are mainly involved in monitoring the machines whereas in the latter two operations workers feed material into the machines. Of all the automated operations in both apparel factories, only the hooking operation represents sewing per se. The challenges of pliability and short seam lengths are overcome in the case of the automated sewing of hook and eye fasteners in that closures are sewn onto semi-rigid patches of fabric. At IndApp2, automated spreading and cutting are also implemented, though some cutting remains manual. In addition, IndApp2 has implemented an automated hanger system for delivering cut pieces of fabric to sewing stations as a central component of its lean production system.

The production process for both footwear factories studied in Indonesia is also similar to each other and comprises producing the sole, cutting and stitching the upper, and attaching these two parts together to produce a shoe. IndFtwr1 uses an injection machine to produce soles. At IndFtwr2, an extrusion machine produces rubber sheets which are turned into soles through a hot-pressing machine and trimming. In both factories, upper components are cut using manually operated machines, though IndFtwr2 has automated the cutting process to some extent. Components are then sewn using manual and semi-automated machines. At IndFtwr2, the back of the sports shoes is moulded manually with a universal press machine to create a three-dimensional shape. Soles and uppers are then joined with heat bonding (they are put through an oven as part of a “primarying” process) before they are attached to each other manually using glue or cement. The attached product is then put through a pressing machine to secure the bond. The shoes are then laced and packaged. At IndFtwr1, the footbed is finished by grinding extra fibres against a small spinning grinder before being packaged.

In **Romania**, sock production at RomApp relies on two types of robots, the circular knitting robot, and the ironing robot. Socks are digitally designed, and parameters defined to programme the knitting robots. Workers manually feed yarn to the circular knitting robots which produce complete socks. Socks are then manually placed on individual supports fixed to a conveyor belt which automatically transports them through three processing chambers for sprinkling, vaporizing, and pressing. A robotic arm separates the socks from the supports and pairs them. Socks are then manually checked for quality, labelled, and packaged. At RomFtwr, shoes are digitally designed. Then, the upper is produced, including fabric cutting using automated or semi-automated machines. Sewing guidance is marked on the cut pieces by hand if these were cut using semi-automated equipment, or automatically if using the automated cutting machine. The upper components are then sewn together, heavily relying on workers’ dexterity given the small and varying size of parts and the variability of sewing directions. This process is followed by punching holes where eyelets will be attached using semi-automated machines. Next, natural rubber (crepe) is mixed with fillers for vulcanization via an automatic process. Then, this is pressed with an embossed cylinder resulting in sheets of rubber with a particular design. Rubber outsoles and foxing/toe caps are cut from the embossed rubber sheet using cutting knives and semi-automatic cutting machines. The assembled shoes are manually placed on the shoe lasts on the conveyor belts that transport these shoes through a heated air tunnel, which dries the manually applied adhesive. Then the shoes are further autoclaved prior to being manually taken out of the shoe last. Finally, the shoes are pressed using semi-automatic machines, logos are manually print screened on insoles, sizes are stamped, insoles are manually inserted, silicon is applied on the rubber, and quality control ensures the shoes are ready for packaging.

In **Spain**, production at SpaApp is like that of RomApp described above. In turn, the technologies deployed by Spanish and Romanian footwear manufacturers differ, beyond the digital design. At

SpaFtwr, materials are cut either with automated or mechanic machines, depending on the material and volume required. Cut pieces are manually marked to guide sewing. Leather is mechanically polished, and then the sewing process starts. Semi-automated machines can cut thread and make loops, while embroidering is automated. Final assembly counts with a conveyor belt to transport goods from one step to the next. Some steps are manual, such as insole insertion, glue and silicon application, while others are semi-automated, such as pressing machines for adhesion. Finally, shoes are manually removed from lasts, controlled for quality, cleaned, and packaged.

In **Germany**, specialized software is used for product design and prototyping. Fabric spreading and cutting is automated, with different machines used depending on the type of textile and component to be cut (e.g. belt cutting machines for zippers). Operators manually transport cut components to be assembled at the sewing section. At GerApp1, semi-automated sewing machines are programmed to stop sewing at a specific length and to cut the thread. Next, the product is finished, labelled, checked for quality and packed, all of which are done manually. GerApp2 uses several automated processes in assembly, such as the automated pocket setter, which automatically positions the pockets by sewing them together – one worker supervises multiple robotic arms. These robotic arms are still in the adjustment phase, and, at the time of the interviews, they were 25 per cent less productive than workers manually sewing pockets. Other sewing steps are semi-automated, such as sewing together the front and the back of trousers, and require a worker to manually manipulate fabric through semi-automated equipment. Each sewing table counts with a robotic arm, developed by factory experts, picking up the sewn components and transporting them to another section. GerApp2 also owns a robot-assisted warehouse with robotic arms that pick and place rolls of fabric on shelves.

Drivers and barriers to automation and technological upgrading

The case studies revealed several factors which may support or discourage automation. Increased and consistent product quality, greater efficiency and competitiveness were factors frequently identified as encouraging technological upgrading. In addition, various concerns over the workforce – including a dearth of skilled workers and high or increasing labour costs – emerged as contributors to efforts towards automation. At the same time, various factors hinder technological upgrading throughout the countries and establishments studied. These obstacles fall largely within two categories: technological feasibility and economic feasibility. The remainder of this section explores these findings.

Drivers

In **Mexico**, technological upgrading across the factories studied took place in context of an expansion of production and were expected to delivery greater productivity and output capacity, producing efficiently, and delivering quality products quickly. In multiple cases, informants linked automation to firms' business proposition and to commitments to lean manufacturing. Furthermore, in one of the footwear manufacturers, the relationships with technology developers and the establishment's ability to test equipment before committing to its adoption was highlighted:

“Given our excellent prestige as customers, machine manufacturers send us, from time to time, machines on try-out periods, to ask us whether they are suitable for our manufacturing processes... some footwear manufacturing firms take us as an example and try to buy the same machinery and brands that we use.” (male manager, MexFtwr2)

Concerns over the workforce figure prominently among the automation drivers in the Mexican case studies. On the one hand, labour shortages in the industry and difficulty to attract young workers was consistently reported to foster automation. Automation is perceived as a tool to allow workers to move from tasks which can be automated to other tasks, and to improve working conditions to make the industry more attractive to workers. At the same time, it transpired from an interview with a male manager from MexFtwr2 that technological upgrading in some operations was driven by labour costs, at least to some extent: *“In cutting, the decision to invest in more automated machines were cost efficiency and labour saving”*.

Interviews in **Indonesia** indicate that automation has been introduced to improve product quality and consistency, productivity, and cost competitiveness. It was remarked, for instance, that output per worker doubled with the introduction of automated (blade) cutting at IndApp1, while at IndFtwr2, semi-automatic sewing has doubled speed and output compared to manual operations. Reduced errors and lower rejection rates and waste resulting from greater precision and efficiency contribute to sustainability and cost management, according to interviews from both apparel and footwear factories. In some cases, as indicated by interviews at IndFtwr2, automation is driven by the requirements of new products, such as a digital printing machine for intricate patterns which would be too difficult to do manually. In IndApp1, it was also suggested that technological upgrading and automation allow the establishment to increase output within the current floorspace constraints. Management at IndApp2 also indicated that a key driver of technological upgrading is complying with buyers' corporate social responsibility initiatives. In this regard, they indicated that the focus on productivity is linked with a "high-road" business strategy, complying with national and international labour law, including on minimum wages. Digitization, in the form of information collected by IndApp2's automated hanger system, helps identify bottlenecks in production and set the pace of work. In all four factories, minimum wages were identified as a concern linked to technological upgrading.²¹ A manager from IndFtwr1 summarized the roles of demand, budgets, and flexibility in automation decisions:

"There are three factors, the first one is based on the demand, is there need for the new technology? The second one is that we have to make sure that the machines will increase our productivity by studying them beforehand. When the productivity is high, then we will consider the budget. ...so, before we buy a new machine, another consideration will be also the sustainability of the machine. How long can we use the machine and is the machine flexible enough to follow the dynamics of the models. So all the machines that we have are machines that are flexible." (male manager, IndFtwr1)

Output quality emerged as key from case studies in **Romania**. Interestingly, in one of the establishments, RomApp, quality improvements trumped costs in the decision to purchase the most modern technology. The automated circular knitting robot with a closed tip is more expensive than the non-automated, less productive equipment. However, improvements in the quality of the fully machine-made sock versus those produced with sewn tips led the establishment to upgrade the production technology with a view to improve competitiveness. Generally, improvements in quality were linked to the standardization of processes achieved via automation, associated with precision and repeatability as well as reduced errors, as summarized by an informant from RomFtwr. Closely linked to quality was efficiency and productivity which would translate into greater profits. Among other factors, these would be achieved via automation, by the elimination of auxiliary and time-consuming tasks that interrupt or delay the production process, such as picking a tool or changing the body position. Automation also leads to better working conditions and environment, with cleaner spaces and processes, and less physically demanding tasks, another stated goal of automation according to interviews in Romanian establishments. It was also remarked that lower specialized skills requirements for handling automated machinery (vis a vis manual processes) would both address concerns over a dearth of skilled workers, such as sewing machine operators, and make work in the industry more attractive.

"What is good about the robots we are working with is that we do not need to know how to perform traditionally manual jobs. We just need to know how to manipulate the machinery. For example, the knitting robot is more complex, and you need a mechanical basis, but the ironing robot is easy to learn how to operate" (woman worker, RomApp)

²¹ It must be noted that some of the factories have moved location at some point in time in search of lower minimum wages as these are set by region.

Unanimous among the drivers mentioned in interviews in **Spain** is product quality. Competitiveness, in some of its various dimensions – including superior and consistent quality, efficiency and reduced errors via standardization of the production process, and higher productivity – appear to be at the centre of automation decisions in the Spanish establishments. Competitiveness was also connected with the ability to produce differentiated goods in the sock manufacturer, SpaApp: *“In order to face the growing presence of Chinese products, we decided that we should produce high-end products that would differentiate [us] from competitors. Therefore, the main objective of the company was to focus on research processes and the acquisition of the latest technology”* (male manager, SpaApp). Informants also highlighted other benefits of automation which contribute to profitability, including shorter production cycles, as well as quicker product design and prototyping, and lower power consumption. Another important driver relates to the limited availability of specialized workers, particularly for tasks which have historically required skilled workers, such as sewing and cutting. This concern is also being addressed by public training programmes established in recent years, geared towards manual skills and machinery operations.

The case studies from **Germany** indicate that a key automation driver is the “made in Germany” factor. This relates to reshoring, progressively reducing dependency on third countries, as well as to responding to increased demand for European products, which are associated with high quality. In context of relatively high wages, competitiveness requires lower labour content and, thus, drives automation efforts. Workforce concerns addressed by automation extend beyond wages. For instance, the recently established GerApp2 had its location chosen strategically, to take advantage of the supply of specialized foreign labour in the adjacencies. At the same time, interviewees remarked that technologies lower the skills requirements of tasks, as well as their physical demand, allowing workers without special skills and older workers to engage in the industry. In such a scenario, automation is seen as a necessity for the future of the industry, as remarked by a specialist at GerApp1.

In the German cases, interviewees believe that, in the longer-term, increased efficiency, quality and productivity per worker, and reduced waste, lead to savings, and thus automation is seen as economically advantageous. Respondents from both German establishments stated that, ultimately, the goal is to fully automate production. The products produced by both businesses under study facilitate automation within the current technological feasibility constraints. It was noted that the goods produced by the two German establishments are relatively standard – for instance with some variation in the finishing, in the case of jeans – which facilitates automation. A favourable ecosystem, including close relationships with technology developers, also contributes to automation.

“Most models are very standardised. And that was also the reason to start with denim because the denim you have, style variation is quite limited [...] Jeans is quite a complex product, but with a high automation potential because it has a standard size and the fashion in the jeans is coming via the laser and the washing and so on. But if we have it a little bit wider and slimmer, it doesn't matter. The production is always the same.” (male manager, GerApp2)

Barriers

In the cases studied in **Mexico**, barriers which inhibit automation in both apparel and footwear factories encompass the (lack of) standardization of tasks, difficulties in material handling, and variations in production volumes. For instance, in MexApp1, plain fabrics are cut by automated steel-blade machines whereas manual cutting is used for checkered or plaited fabrics and combed textiles; in turn, informants from both footwear establishments reported difficulties in the automation of leather processing. Existing technologies were also identified as often unsuitable to produce small batches of niche goods. At the same time, the value proposition of some of the Mexican establishments under study relates to handmade, custom or small-batch apparel or footwear which, by definition, limits the extent to which automation technologies can be used. In these cases, automation is limited to some standardized sub-operations. Rapidly changing apparel and footwear products was also

pointed to as an obstacle to automation. Still, it was noted that some standardized sub-operations can be automated.

“Standard processes can be automated. In apparel manufacturing, although fashion forces frequent modifications, there are many operations that are quite standard. For example, sleeves are made separately so are their eyelets and ‘angles’, as well as the attachment of some components in the necks or elbows: all are processes of few rather standard operations.” (male manager, MexApp1)

Nonetheless, technological feasibility is not sufficient to justify automation. At MexApp2, managers indicated that existing options to further automation have been found not to be cost-effective and that, therefore, the establishment decided not to deploy it. Costs and the lack of support for financing innovation (with the need to fully rely on own resources) have been found to curb technological upgrading and automation. Costs related to changing the layout of the manufacturing floor are another barrier. Technological upgrading at MexApp1 required significant modification in the plant’s layout and work organization. Further changes would imply additional costs.

Several barriers emerged from the research in **Indonesia**, including issues related to materials and available technologies. In addition to the general pliability of fabrics, which has thus far hindered advancements in automated sewing, the delicate and often slippery nature of underwear fabric as well short runs of fabric, have led to the continuation of manual cutting, one of the operations where automation technologies have advanced furthest. In footwear too, materials limit automation. IndFtwr2, semi-automatic sewing does not work for very soft materials and tiny parts and stitches, such as for children’s shoes for which manual stitching is better suited. Furthermore, leather and parts which necessitate greater accuracy require manual cutting. In many instances, products are compatible with current or older machinery precluding the need for upgrading and automation. As stated by a male technology specialist from IndApp1, *“Actually, we are currently still looking for the suitable technology that can be used in the sewing process. If we found the right one, then we can do some trial to study the machine before we implement it”*.

The cost of machinery, including maintenance and part replacement, is another impediment to upgrading according to interviews at Indonesian apparel manufacturers. This is also linked to the great variation in patterns and models, with constant changes, requiring flexibility and adaptability in production. It was argued by informants from IndFtwr1 that manual processes still provide the most flexibility, and the decision to automate depends on balancing and weighing the risks of financial investment and demand with productivity gains.

In **Romania**, the high cost of equipment coupled with low profit margins, the time required for a return on investment, and relatively low-cost labour means it often makes more sense, financially, to increase the workforce rather than to update machinery. As reported in interviews, public support was essential to kickstart automated production in the apparel establishment, with a subsequent slow increase in the number of robots. Moreover, an informant stated that equipment is only updated when obsolete, rather than according to new technology releases. Operationally, depending on suppliers for equipment maintenance and repair is perceived as a costly hindrance. Costs linked to training workers to operate new equipment and idle time are also weighed in automation decisions.

The in-depth case studies in Romania also feature technological feasibility as an automation barrier. Pliability and other fabric characteristics were mentioned, combined with the variety of products and consequent need for flexibility in production. Even for knitted apparel, where the presence of automated equipment surpasses that in non-knitted apparel, significant limitations remain, associated with difficulties in reproducing human dexterity: *“Total robotization in this sector is challenging due to yarn feeding, as it would need a robotic arm capable of perfectly imitating the human hand when feeding yarn to the knitting machine”* (male manager, RomApp).

In the **Spanish** establishments, the most important barrier to automation is economic. Interviewees remarked that profit margins are low, the industry has fluctuating demand, and fierce competition

with foreign manufacturers impedes a hike in product prices, thus complicating the financial commitments required to upgrade production equipment. As reported by a male manager at SpaFtwr *“If there would be higher demand and continuity in the production level, we would implement more automation to be more efficient and reduce costs, if the demand is variable, we will not take the risk to invest in automation”*. Costs include the purchase of equipment, as well as implementation costs linked to training workers and maintaining and repairing machinery, which involves elevated service prices from external suppliers. Similar to the Romanian case, financial support, in this context from the regional government, was vital for the first investments in automated technologies by SpaApp. The limited availability of machines which can handle yarn and knitting or sewing was also stressed by respondents in Spain. Automation is, according to informants, complicated by the malleability of textile materials, and variations in product sizes and models, which require dexterity and versatility.

Chief among the barriers discussed with **German** informants are costs for purchasing and implementing equipment, coupled with limited financial support. A dependence on equipment suppliers for maintenance and repairs augments cost concerns. Costs are further compounded by those associated with training, which involves times during which workers are not producing. Another critical issue is the limited availability of automated machinery suited for apparel production. It was remarked that automated material (i.e. fabric) handling remains elusive, a challenge further complicated by frequent changes in fashion trends which prevent running the same production process over the years. An additional concern relates to the synchronization of software and mechanical equipment. In this regard, technological incompatibility may hinder digitization and automation. Moreover, automated equipment for apparel and footwear production is, in many cases, new, which can lead to a lack of trust from companies given uncertainty regarding suitability and cost-benefit. These concerns are summarized in the following excerpt:

“There is a high interest in automation of the production process, but without capital to finance the machinery, it is exceedingly difficult [...] The software generates a problem because it is not revamped. That is why the company wanted to change, but it is relatively costly. The machine [cutting] is also expensive because it requires maintenance from Switzerland.” (male technology specialist, GerApp1)

Finally, while “made in Europe” or “made in Germany” was identified as a driver of automation, it is also thought of as a barrier to the extent that it is difficult to communicate the added value of a locally produced garment or footwear, and therefore, demand remains limited.

Automation impacts on employment, quality of work and the gender division of labour

Automation affects many dimensions of employment. The following sections discuss each of the main impact areas separately, namely: employment numbers, skills and training, contracts, wages, and working conditions. Special attention is devoted to differences in impacts for women and men production workers.

Labour substitution

In **Mexico**, data collected in interviews with the various establishments indicates that there is some labour substitution at the task level associated with automation but, to date, the expansion of demand and production capacity has more than compensated the labour substitution effect of automation. It was reported that, at MexApp1, each automated cutting machine can substitute between eight to ten workers. Similarly, at MexFtwr2, engineers remarked that recently added robots for direct injection and for cleaning the moulds decreased the number of workers needed for these operations from 25 to 8. However, in both cases (and in the other establishments), given that the adoption of new machinery has taken place at times of growing demand, it has not been accompanied by a decline in the number of factory workers, but rather to the reassignment of workers to different tasks. Technological upgrading and automation have, however, led to shifts in the profile of the workforce.

The dynamics of job destruction and creation are summarized in the following excerpt from an interview at MexFtwr2:

“Our automated machines substitute some workers, but at the same time create other positions with different qualifications, in particular to operate the machines and to give them maintenance. And the automated machines allow MexFtwr2 to produce more and meet higher demand; thus, their introduction may create employment in net terms. To the extent that these new workers are more qualified, their remuneration will be higher. So, more than a net substitution effect of labour by automated machines, we have trade-offs, it destroys some jobs, but it creates other jobs” (male engineer, MexFtwr2)

In **Indonesia**, the apparel factories studied experienced a displacement of workers at task level, with fewer workers per machine, but not at the factory level. Workers whose tasks were directly displaced by new technologies were reassigned to other tasks and trained as needed, given that automation happened in context of growing demand and the need for output increases. For instance, at IndApp2, with the introduction of automated cutting, the worker-machine ratio fell from three to two, while output per machine is three times as high. Yet when inquired about this displacement, neither women nor men working in these factories expressed much concern about losing their jobs because of automation. At the footwear factories, there are different dynamics at play. At IndFtwr2, management made an agreement with the union not to retrench workers because of technological upgrading, but managers revealed the need to raise productivity and quality to keep up with the rising minimum wage. As a result, working hours were significantly reduced, and rehiring when a worker quits became less frequent. Given the lack of time series data on employment at the footwear establishments, the research could not confirm whether or not the workforce has contracted as a result of automation.

At the **Romanian** establishments, it was reported that automation did not result in important changes on net employment, and that the number of employees in the two factories has remained constant. However, automation impacted the type of jobs, how work was organized, and tasks conducted. New jobs were created to monitor and programme machinery, as well as to operate specialized equipment and software. Careers prospects arguably improved, and interviews with both managers and workers suggest a positive perception of automation technologies.

“When I first started to work here, I was operating knitting robots, but as the number of robots increased, more operators were hired, and finally it was needed to create the position of technical director for supervision, management, difficult problem-solving, so I managed to grow in the company.” (male supervisor, RomApp)

Interview findings from **Spain** support the idea that automation does not necessarily have a negative impact on the number of jobs but affects their characteristics and task composition. On the contrary, a supervisor from SpaApp stated that the firm had to hire more workers to keep up with production and sales volume increases thanks to the implementation of automation technologies. The transformation of jobs requires, however, training and/or the reassignment of workers across the factory floor. New jobs, such as yarn feeding or parametrization of circular knitting robots present career progression opportunities to which workers can internally apply and receive training for. New specialized positions, such as for computer-aided design or IT-related posts also tend to emerge. Interviewees from SpaApp indicated that job changes can make the industry more attractive to young workers, while informants from SpaFtwr remarked that those who apply for positions are frequently late career professional, in their 50s and 60s, coming from companies which close operations, and thus for whom career progression may be difficult. From a gender perspective, due to the fact that there is a clear female-male task distribution, with male predominance on technological tasks, it can be assumed that male workers have, in principle, more possibilities for career advancement. Nevertheless, there are also women using new technologies who are presented with the same opportunities for applying for job changes or career improvements.

“We had to create a new job for the parametrization of the new designs of the products as inputs for the knitting robots, and this is an intermediary step between the digital design and robot programming. This is a necessary step that allows robot programming. This is the same process as when we included digital design and had to create a specialized department for this task.” (male manager, SpaApp)

Findings from the two **German** case studies indicate that there is some labour replacement at the task level. For instance, it was reported that each semi-automated sewing machine – which count the steps operators perform, automatically stopping and elevating the support system at the end, and cuts the thread, stopping the process – does the work of three operators. In other cases, the substitution of labour input by machine input and simultaneous simplification of tasks allows a worker to multitask:

“The robot that is taking the pockets, to fill this robot needs maybe 10 minutes to put all the pockets in the right place. And then that person can do something else. So, the variety of jobs will be far wider. So, one colleague is serving three machines at the same time.” (male manager, GerApp2).

It therefore transpires that automation transforms jobs, changing their task composition and how these tasks are performed. In spite of these shifts, the case studies do not indicate changes in employment numbers because of automation and technological upgrading. In the case of GerApp2, this is potentially because the factory was established recently, and with a high degree of automation from the start. It emerged from German cases that automation has positive, albeit indirect, impacts on career prospects to the extent that it is accompanied by greater production volumes necessitating the creation of new jobs, including specialized and supervisory roles.

Skills and training

The introduction of new equipment at apparel and footwear manufacturing plants changed the skills requirements of workers in **Mexico**. In some cases, tasks became simpler. For example, it was reported that training a worker for manual cutting requires 16-24 weeks while a worker can be trained to operate an automated cutting machine in 2-4 weeks. In other cases, workers feed materials and components to the machine, which carries out the sophisticated processes, as reported in the case of fusion machines. Some skills upgrading is also required, e.g. electronic panels added to some sewing machines require that operators learn to use computerized screens, in addition to the traditional dexterity required for sewing. In other cases, specialized education is needed, e.g. at MexFtwr2, robots for direct injection and cleaning moulds require employees specifically trained to program and monitor the equipment. It was highlighted that the introduction of semi- or fully automated machines offer workers the possibility of acquiring more, different skills, and of having the capacity to execute multiple tasks. Informants from all factories highlighted that establishments focus on training multiskilled workers who can operate several machines for a variety of tasks from laying fabrics, to cutting, trimming, and fusing, as reported by workers and managers at both apparel and footwear factories. Multiskilling facilitates workers’ reassignment with the introduction of new machinery, particularly in the Mexican context of labour shortages, and facilitates career progress, including wage rises:

“I started ironing, then I went to the fusion machine. I also now have the skills to carry out other tasks, e.g. half-moon as there is not much work, we must be very skilful and ready to do different tasks and operations. That is why managers began to teach me how to operate different and new machines. And as I acquire such abilities to handle the machines, I have a somewhat higher salary” (woman worker, MexApp1)

In **Indonesia**, it was reported that, generally, there are no education requirements for operating automated machinery – most workers have a high school diploma or equivalent vocational education – and training is provided in-house by equipment suppliers and can be considered skills upgrading. In other cases, semi- and automated technologies may lower the need for specialized skills, e.g. workers operating semi-automated sewing machines at IndFtwr1, according to a manager, do not need to rely

on advanced sewing skills; rather, they need to place fabric on palettes efficiently. However, in some instances, working with new machinery may require higher skills, e.g. mechanics hired by IndFtwr2 are now required to be computer and programming literate. Managers at both footwear factories highlighted the need for multiskilled workers who can operate more than one machine and can be flexibly allocated based on demand.

The need for training and reskilling workers also emerged in the case studies in **Romania**, associated with changes in the organization of work. This training is most often imparted on-the-job with some exceptions. At RomApp, workers receive three weeks of training on how to manipulate machinery and perform tasks. Some jobs require prior (outside) training, such as operating knitting robots, which necessitates a mechanics background. At RomFtwr, supervisors provide factory floor workers training in-house, and when new equipment is installed, some training is provided by the technology supplier.

The **Spanish** case studies concluded that the tasks that workers perform tend to be simplified by new technologies – be it robotization, mechanization or digitization – due to the partial replacement of manual tasks with automation, which may facilitate job rotation. For example, knitting robots at SpaApp produce complete socks with yarn fed by workers, in turn, working with ironing robots requires that workers place socks on moulds which an automated conveyor belt transports through a steam and ironing chamber. It was stated that due to task simplification, no specific skills and capabilities are needed to enter the industry. Training, it was reported, is provided by the factories. However, it was also remarked that basic knowledge of manual operations facilitates adaptation, and that certain processes necessitate specialized knowledge, such as knitting, cutting, or computer-aided design. Moreover, workers can effectively become machine supervisors, responsible for one or multiple machines, which may lead to increased responsibilities or greater task complexity.

As in other countries, in **Germany**, automation was associated with a simplification of tasks. This concerns workers simply feeding machines material, as well as the partial substitution of labour input by machine input, often for routine, repetitive, intermediate steps, such as sewing machines which automatically cut thread. This is often linked with a lower need for specialized skills, with workers focused on machine supervision and/or feeding (materials) for which they can be trained in-house. At the same time, other tasks may become more complex, due to the need to operate advanced machinery or to resolve technical issues which may arise. For example, the design, pattern making, and cutting section of GerApp1 necessitates specialized workers to operate advanced software and machinery. Moreover, it was noted that more science, technology, engineering, and mathematics (STEM) workers will be needed.

Contracts and wages

None of the case studies in **Mexico** suggest that contract type and wages scale are influenced by technological upgrading. The workforce in all establishments is comprised of wage workers, with base pay linked to the national minimum wage and adjusted to the task performed and productivity. Although wages are linked to tasks, it was consistently stated that wages are not linked to the type of machinery used. At MexFtwr2, a comparative evaluation of the dexterity required for each job/task in the sub-operations of manufacturing was conducted, and those of higher difficulty are linked to higher pay – this is not systematically linked to type of equipment workers operate or the degree of automation. A worker stated that some tasks that require more specialized manual work are paid more, e.g. sophisticated backstitching operations. Still, workers reassigned to new tasks due to technological changes may experience wage increases, as reflected in the worker interview excerpt presented in the discussion of skills and training.

Unlike in other countries, in the **Indonesian** case studies, three of the four factories use contract workers, though the majority is regularly employed, with associated benefits. The fourth factory engages only permanent employees, a buyers' requirement. The research in Indonesia did not find a clear relationship between operating new machinery, earnings and career prospects. It emerged that the wage structure within factories is compressed, and that automated machinery is only one of many

factors which may affect earnings and promotion opportunities. The default starting wage is the regional minimum wage, and increases can be linked to workers' tenure, hierarchical position (e.g., operator, supervisor), whether they received training for and operate new machinery, hours of work, and performance.

In **Romania**, it was remarked that labour costs are low relative to investing in new equipment and upgrades, and that there is a general culture of trying to create and maintain employment, in a context of limited socio-economic development. Findings on the impact of automation on wages are mixed. Automation impacts wages at RomApp to the extent that workers' pay is linked to the factory's output. At RomFtwr, wages differ with the tasks conducted, with the machinery involved, and the worker specialization.

In **Spain**, informants highlighted that wages are defined by sectoral agreements, and foreign competition has historically led to adjustments. Wages in the two establishments studied were not impacted by automation. They are, instead, defined according to workers' jobs and attributions. Although most workers are regular employees, the footwear factory counts with subcontracting mainly for sewing and assembly operations, reportedly due to cost considerations.

Regarding wages in **Germany**, it was reported that workers' pay is defined according to their jobs, qualifications, and labour law. GerApp2 indicated that they could produce garments in Bangladesh at lower costs but preferred to bring production back to Europe.

Hours of work

Hours of work are another key dimension of employment quality which can be impacted by technological upgrades. In **Mexico**, these were arguably not affected by upgrades except in the cases of automated cutting machines at MexApp2 and state-of-the-art robots for direct injection and cleaning moulds at MexFtwr2, which operate 24 hours and require constant monitoring by a specialized worker. However, regular working hours are long and it remains common practice to impose additional work hours weekly, over and above those specified in formal contracts, to meet production targets, which may be particularly disadvantageous to women: *"... the industry has a tendency to impose long or extended work hours: a tendency that is unfavourable to women, and makes it more difficult for them to have compatible, functional work-family commitments on a day-to-day basis"* (male manager, MexFtwr2).

In **Indonesia**, long working hours are common in apparel and footwear manufacturing. Although the full-time workweek is 40 hours – eight hours per day, five days per week – daily overtime or an additional shift on Saturdays are common during busy periods. In one of the footwear factories, IndFtwr2, an agreement not to dismiss workers due to automation has led to significant reductions in working hours. Semi-automated stitching saw the largest decline in working hours, with clear gender implications given that women are the majority of workers in these operations.

Regarding working times, the two **Romanian** factories differ. While the hours of work have remained unchanged at RomFtwr, with a single shift per day, the continuous operation of machinery at RomApp implies morning and night shifts, which may inconvenience employees and impact work-life balance.

In the **Spanish** establishments, the effect of new technologies on working hours varies. For many workers, the length of shifts declined from ten to eight daily hours due to the greater fluidity and efficiency achieved through automation. An exception occurs with workers operating knitting robots, which operate continuously, thus requiring that workers work different shifts, with implications for work-life balance.

In **Germany**, working hours were not, according to informants, affected by technological upgrading and automation. Firms' working hours are fixed and have remained unchanged. However, it was suggested that automation could change employment patterns. In this sense, it was reported that at

GerApp2, management is considering the possibility of automation facilitating the hiring of older workers part time, by lowering the skills needs and physical requirements of work.

Working conditions, safety and health

In **Mexico**, it was reported that more modern machinery decreases the physical strain of workers. For instance, semi-automated sewing machines require the use of a single pedal, in contrast to two pedals in the traditional overlock machine. It was also remarked that some automated machinery used for footwear production reduces the physical effort required for the task, which can lead to a greater proportion of women in formerly physically demanding tasks.

In **Indonesia**, new technologies have simplified work and made it easier, according to managers and workers. Moreover, workers interviewed in apparel and footwear factories expressed a preference for working with the new equipment. For instance, an apparel worker stated that operating an automated cutting machine is easier than working with manual cutting, in line with a statement by a technology specialist which suggested that workers' jobs become easier with the new machinery. However, a worker at a footwear factory, who stated that it is easier to work with the semi-automatic sewing machine also remarked that it increases the work speed, leading to sore hands. In some cases, the speed of machines has been reported to have caused accidents in the footwear factories. There is also some evidence of intensification of work linked to the automatic hanger system at IndApp2, which allows for close monitoring of workers.

Findings from the **Romanian** case studies suggest that new technologies affect various dimensions of work quality, including autonomy, pace of work, safety and health. The standardization of work – with stricter patterns for task execution, often concomitant to a reduction in task complexity – is associated with a decrease in workers' autonomy and with a set work rhythm. Sewing machine operators, for example, albeit aided by new technologies for subtasks such as cutting thread, must continue to manually guide fabrics through the sewing process, at arguably increased pace. Findings indicate that work rhythm and intensity are also determined by the number of pieces of equipment under the responsibility of a worker. At the apparel factory, the data collected via automated and digitized systems allow for more closely monitoring work processes and, therefore, indirectly, workers. Although greater monitoring and less autonomy may be regarded as drawbacks, they may also be perceived as positive outcomes from automation, as remarked by a worker:

“I don't need to think [about] how to do the job as the steps are already predefined, and for me it is easy and comfortable this way. Nevertheless a machine imposes constant speed, but a human cannot maintain it for the whole workday, and there it needs to be modified” (woman worker, RomApp)

Findings on ergonomics and work environment are mixed. For instance, at RomFtwr, the automated design/cutting process replaces the physically demanding tasks of drawing and cutting on a table. On the other hand, at RomApp, knitting robot operators need to stand for nearly their entire shift. In terms of the work environment, modern equipment is perceived to improve safety at work, with lower risk of injury. However, loud noise and heat generated by the robots were observed during the site visit.

In **Spain**, the case studies concluded that rigid standards fixed by automated equipment reduces workers' autonomy, given the standardization of the workflow and rhythm, and can increase the pace of work, originating additional pressure on workers. Regarding work rhythm, a worker stated:

“We need to follow the rhythm imposed by the conveyor belts, for example, and place the shoes at a constant pace. Also, we need to process the input of

intermediary products received from the previous section in a specific amount of time, to be ready for the following processing section. So the rhythm is imposed by the machines, and also the constant speed of work is a bit difficult for us to maintain for so many hours.” (woman worker, SpaFtwr)

According to findings, in addition to work pace, greater pressure may arise from monitoring an increased number of machines. Moreover, digital technologies which often accompany hardware solutions result in greater monitoring and control over employees' activities, with implications for workers' autonomy. However, interviews with workers suggest they do not feel negatively impacted, e.g. *“I don't feel uncomfortable by the increase of work control of the new automatic machines”* (male worker, SpaApp).

Ergonomics and the work environment are also influenced by the equipment used in production. Findings from the Spanish cases suggest some improvements in working conditions have been observed with technological upgrading, for instance via the automation of previously labour-intensive tasks, such as cutting. But in other instances, such as for those working with the knitting robots, it is necessary to keep a standing position. A reduction in machine-related injuries due to automated safety systems was also reported. Moreover, machines have replaced workers in some dangerous and toxic tasks, decreasing contact with chemical products. Nonetheless, negative impacts from noise and heat generated by machinery were identified as a concern.

In **Germany**, interviews revealed information on several dimension of work quality. In terms of occupational safety and health, technological change has been accompanied by improved ergonomics and postural health, although it is debatable if static positions next to machinery are a positive evolution. For example, in GerApp2, the factory counts with a “waterfall system” where trousers are positioned to avoid that workers bend to grab them. In terms of occupational safety and health, it was also noted that automated equipment is less noisy and reduces toxic emission; on the flip side, workplace temperatures increase with the constant use of automated machinery. Automation is also linked with increased and consistent work rhythm and to potentially greater pressure from monitoring multiple machines at the same time. The standardization of tasks, via automation, also leads to a reduction in autonomy. Moreover, automation has been accompanied by digitization, and the digital management of production results in greater capacity to monitor and control employees.

The gender division of labour

In **Mexico**, informants from the apparel and footwear factories stated that there are no gender requirements associated with job posts, yet gender segregation across tasks is a common reality. For instance, in apparel, most workers in sewing are women while cutting is disproportionately male; in footwear, most workers in finishing are women whereas the majority of workers shaping heels are men. Interviews with workers and managers from both sexes reveal stereotypes which may be underlying this gender segregation. For instance, a women worker stated that women tend to be more careful than men when backstitching, embroidering, ornamenting, and sewing. A manager recognized that cultural norms play a role in the gendered division of labour within the factories. According to the manager, *“except in some physically strenuous operations, the share of women tends to be culturally determined and not related to differences in productivity or in capacity of men and women”* (male manager, MexFtwr2). To date, technological upgrades have not had major impacts on the traditional division of labour within the apparel and footwear manufacturers. In terms of working conditions, findings indicate that hours of work have not been directly affected by automation, and remain unfavourable to women workers, as remarked by a manager who argued that the industry tends to impose long or extended working hours which makes it difficult for women to balance work and family commitments.

During interviews in **Indonesian** factories, informants, including women workers, stated that women and men are treated equally. When probed about the *de facto* gender segregation across tasks,

interviewees provided varied responses. Managers argued that women may be better suited than men for sewing operations because they are more patient, detailed oriented and careful. In turn, a woman human resources manager and a union representative suggested that it is just a coincidence that the sewing department has more women than men. Regarding the predominance of men in cutting or printing, it was indicated that the activity is physically demanding and somewhat dangerous and thus “better [for] men workers to handle”. It was also suggested that more women apply to certain jobs, such as sewing operations, and therefore there are more women in those departments. Another reason for persistent gender segregation relates to carry-over effects. At IndApp1, it was argued that automated hooking operations (a type of automated sewing) is largely done by women because they were the ones who previously performed this work manually. Notwithstanding, some improvements were observed, even if marginal. One of the three supervisors for the automated hanger system at IndApp2 is a women who used to be a sewing machine operator. At IndFtwr2, the deskilling of sewing operations with the introduction of semi-automatic machines has been accompanied by an increase in the number of men applying to these positions.

In **Romania**, it was observed that women mostly engage in sewing, finishing, quality control, packaging, and generally manual tasks, meanwhile, men are concentrated in more mechanical, technical, and physical tasks. Despite the absence of open discrimination based on gender, Romanian informants’ remarks reveal that certain cultural factors shape the roles of women and men. It was argued that job assignments depend on workers skills, but that women are “naturally” more attentive to detail, patient and more creative than men, who are considered better fit for mechanical, technical, and physically demanding jobs. Seen that two of the factors determining wages are a worker’s task and the equipment involved, occupational segregation impacts wages to the disadvantage of women. It was remarked that there are some women engaged with new technologies, but they remain a minority.

Some gender segregation across tasks was also identified in **Spain**, despite interviewees’ remarks that workers’ sex does not influence hiring. The Spanish case studies find that gender implications of automation are linked to underlying cultural norms and expectations which shape to which jobs women and men apply. Informants consistently portrayed the idea that there is no gender segregation, that job openings are genderless, and that anyone with the required skills can perform a task. Yet, comments (by women and men) such as “sewing is a women’s job” and “women are more suitable for quality control because they are more attentive to detail” refer to norms and stereotypes which attribute certain characteristics to women and men. In effect, the case studies found that most technology-intensive tasks are male dominated, while manual tasks are predominantly done by women. Women are distributed in tasks such as sewing, ironing, finishing, quality assurance, packaging, and administrative roles at the bottom of the hierarchy. In turn, men mainly perform physically intensive tasks such as cutting, fitting, and putting the shoe on the last, or tasks requiring advanced skills as machine operators, and higher hierarchical or managerial tasks as supervisors, and CEOs.

“Traditionally in the footwear industry, the presence of female or male workers is defined per section, for example in the cutting section work mainly men and in the sewing section work mainly women... However, with automatic machines, all the processes can be done by men and women since no gender-specific skills are required.” (woman worker, SpaFtwr)

Thus far, the gender division of labour has remained largely unchanged despite technological advances, suggesting that there is a legacy effect at play. For instance, automated cutting at SpaApp is done only by men. Still, some advances have been observed, such as women being hired to adjust the parameters and to operate knitting machines in SpaApp. Future changes may be facilitated by the availability of training to men and women alike.

“In the knitting section we always employed men, but now, due to the public training programmes offered in the area, we count with two women. This is a multitasking job,

counting with the elimination of the physical and intensive tasks that had to be performed previously.” (male manager, SpaApp)

In **Germany** too findings indicate some gender segregation across tasks and occupations, which might be alleviated in the presence of job rotation. At GerApp1, the sewing section is predominantly comprised of women workers, whereas technological tasks are executed primarily by male workers. In turn, at GerApp2, the firm’s focus on job rotation results in greater gender balance across the production process.

The German case studies found that to the extent that physical strength demand declines with automation, task-based gender segregation is decreasing, but women remain underrepresented in management positions. In other words, while horizontal gender segregation might be changing, vertical segregation persists. Interestingly, in Germany, the gender distribution of workers across tasks appears to be connected to the presence of immigrants. Male workers who learnt sewing, cutting and other skills, prior to moving to Germany increase the ranks of men in tasks which are often regarded as women’s, such as sewing: *“There is a very multicultural workforce in the company, with many employees from other regions where, for example, seamstresses are often male”* (male manager, GerApp2). Although it is reported that workers are hired irrespective of gender, solely based on skills, stereotypes emerged, as exemplified by the following excerpt: *“Considering that women are better in STEM than men, it is expected that the number of women in STEM will increase due to automation”* (male manager, GerApp2).

Discussion

We now turn to analyse the patterns and dynamics that emerge from the case studies’ findings presented in the previous section. We focus on how the establishments’ business model and context (i.e. country) shape technological upgrading and automation and on how automation impacts employment and workers. In particular, we discuss findings on employment in terms of gender.

Overall, the drivers of automation largely overlap across factories. Enhanced and consistent output quality and greater efficiency and productivity were mentioned in interviews with all establishments. There seems to be consensus that to remain competitive, firms will need to continue to upgrade production technologies and further automate.

Another common concern relates to labour. In case studies in all countries but Indonesia, a lack of skilled workers (i.e. seamstresses, cutters and other professionals) incentivizes the adoption of more modern technologies which lower skills requirements for those operating production equipment and which releases workers from automatable tasks to engage in tasks which continue to require more labour input. In addition, in Indonesia and Mexico, increasing labour cost was also mentioned as a contributor in the drive towards automation. In many cases, automation is at the centre of establishments’ business models, whether linked to a commitment to quality, high-end products, or, in the case of Germany and Spain, to enable production to take place in contexts where labour-intensive production would not be feasible.

Barriers to technological upgrading in apparel and footwear manufacturing throughout the establishments studied pertain largely to (a) technological limitations in material handling, and (b) costs linked to equipment purchase and maintenance, and workers’ training (including time away from production). The general pliability of fabrics and its varying characteristics continue to hinder advancements in automated sewing and other production processes, issues which have been highlighted in previous literature (Bárcia de Mattos et al. 2020; 2021; 2022; Anzolin 2021; Nayak and Padhye 2018; Altenburg et al. 2020, among others). It emerged from interviews that even in some of the most automated tasks, such as cutting, obstacles remain. This difficulty is compounded by the variety of patterns, models and sizes, and frequent changes in these. That many of the available technologies for the automation of production processes in apparel and footwear are new leads to uncertainty regarding their suitability and costs relative to benefits. Overall, costs related to the

purchase, maintenance and repairing of machinery, as well as to training required to operate new equipment, combined with little financial support, limit the extent to which firms are willing and able to invest in technological upgrading.

In most factories, technological upgrading has been an incremental and fragmented process and full automation is not imminent. Although, by definition, automation substitutes machinery for labour, upgrades in the cases studied have often taken place in context of increasing demand such that this effect has more than compensated the expected labour substitution effect of automation.

New technologies have been found to substitute for labour at the task level (or in suboperations), yet this has not led to worker layoffs in the establishments under study. In most cases, machines collaborate with and complement workers, rather than effectively displacing them. Sewing, one of the most labour-intensive operations in apparel and footwear manufacturing, provides an example. Semi-automated sewing machines automatically cut thread, but a worker is needed to manually guide fabric through the sewing process. In other cases, new equipment effectively substitutes workers, such as automated cutting machines in Mexico. These machines still require an operator but decrease the ratio of workers per machine and increase output in this type of operation. Findings indicate that workers whose tasks became automated have been reassigned to other activities within the factory, in some cases created by the operation of the new machines and in others by the expansion of output. Yet in other instances, changes in employment may be felt through hiring practices. For example, in Indonesia, workers may not be re-hired, while in Germany, one of the establishments has used automated technologies from the start and thus may have hired less workers than it would have otherwise.

It could be argued that fewer workers per machine means that there is implicit labour displacement at factory level. It could be said that employment numbers might have been higher in the absence of automation. However, an equally convincing argument is that this technological upgrading and automation have allowed the factories to remain competitive (regarding costs, quality and volume of production) in a global supply chain which is highly competitive and buyer-led. In sum, the cases studies show that automation is a gradual process which takes place in moments of production expansion, often in contexts where the availability of specialized labour is limited and that, according to case study informants, has not been labour-displacing on balance.

Automation and technological change more generally have led to changes in the composition of the workforce in terms of jobs, the task composition of jobs and their skills requirements. The case studies suggest that as some operations became less labour-intensive (e.g. cutting) the number or share of workers in these tasks declined. At the same time, new positions have been created for operations which remain more labour-intensive, and new types of jobs were also created. This includes, for instance, novel jobs such as for the parametrization of circular knitting robots in Spain. In this sense, one could argue that there are both job destruction and creation dynamics at work, confirming suggestions from literature. Traditional jobs persist, such as sewing machine operators, but their tasks or suboperations may shift, with implications for the skills profiles of workers. There is often deskilling resulting from the simplification of tasks. For example, in one of the footwear factories in Indonesia, the introduction of semi-automated sewing machines lessened reliance on advanced sewing skills, with workers now rather needing to efficiently place fabric on palettes. Similarly, in Mexico, it was reported that whereas manual cutting required 16-24 weeks of training, automated cutting can be taught in 2-4 weeks. In many cases, such as reported in Mexico, Indonesia and Spain, this task simplification allows for multiskilling, increasing workers' flexibility to rotate across the production floor as needed. Upskilling, or the need for specialized advanced training, also emerged as a pattern, especially in regard to the operation of sophisticated automated equipment. This is the case, for instance, of operators of knitting robots in Romania, which necessitate a mechanics background, or with workers in the design, pattern making and cutting section at GerApp1, which necessitate advanced software and machinery training. It can be inferred that the combination of deskilling and

upskilling results in some job polarization, with greater concentration of workers at both ends of the skills spectrum.

Several dimensions of employment quality were discussed in the case studies, including working time, contract type, wages, working conditions, and safety and health. Hours of work appear to have been largely unaffected by automation. All factories studied operate on single shifts. However, there are exceptions. Several of the factories have automated equipment running longer hours, which require that personnel in these operations work multiple shifts. Examples include a robot for direct injection in one of the Mexican apparel factories and knitting robots in Romania and Spain. Moreover, at a footwear factory in Indonesia, an agreement not to terminate workers because of automation has led to significant reductions in working hours. In Spain too automation has led to fewer working hours.

Research findings across the five countries suggest that the extent to which automation influences wages depends on the context and/or establishment. There is no clear relationship between workers' earnings and the technology used at work. In high-income Germany and Spain, findings suggest wages are not linked to automation. In Mexico and Indonesia, earnings are based on the mandated minimum wages and a compressed wage structure means that the scope for influencing wages is limited. Across countries, automated equipment is only one of many factors which may affect earnings, which is often linked to mandated minimum wages and adjusted to workers' tasks, qualifications and productivity.

It was consistently remarked that technological upgrading and automation tend to decrease the physical strength requirements of work. This relates specially to tasks with manual operations that required strength and stamina, such as manual cutting. At the same time, in some cases, operating automated equipment remains physically demanding, such as for workers operating knitting robots for which they are required to stand. In addition, by establishing a constant work rhythm, semi- and automated equipment may decrease workers' autonomy and impose a challenging pace of work. Digitization, which tends to accompany automation, facilitates monitoring and control of processes and, by consequence, of workers, though this was not reported by workers to be a problem.

Research findings from all countries concluded that there is horizontal gender segregation across tasks and occupations, as well as vertical segregation along the job hierarchy. Although we do not have precise breakdowns of the number of women in different operations in the factories studied, informants consistently remarked that some activities (e.g., cutting and knitting) are predominantly done by men while other activities (e.g., sewing and finishing) are disproportionately done by women. Men are also overly represented among management teams. While this is not a novel finding, our research suggests that this division of labour persists in the face of the introduction of technologies which address what have traditionally been professed barriers to women engaging in some of these tasks, more specifically technologies which decrease the need for specialized skills and for physical strength.

Several reasons for this gender segregation and its persistence surfaced. Cultural norms and stereotypes which attribute certain characteristics to women and men emerged in all case studies. On one hand, informants argued that job posts are open to women and men alike and that women and men are equally considered for jobs, training, and promotions. This might be partly a result of social expectations regarding equality and discrimination, but it also appears to be how informants consciously perceive these matters. On the other hand, statements by managers and workers from both sexes reveal that women are believed to be detail-oriented, careful, and patient, while men are perceived as more fit for mechanical, physical and technical tasks.

The supply side also emerged as a driver of segregation, with the suggestion that more women apply to certain jobs, such as sewing operations, while more men apply to other jobs, such as cutting, and therefore there are more women and men in those departments respectively. This suggests that ingrained cultural and social norms may be driving gender segregation by shaping which jobs women and men apply to and get, which training they apply for and receive and, prior to this, which education they choose and is available to them. Finally, another reason for persistent segregation relates to

legacy or carry-over effects, according to which operations which were male- and female-dominated prior to technological upgrading remained so after the introduction of new technologies, as workers in these operations are the ones to be trained to use the machines.

In sum, the persistence of this gendered division of labour suggests that, at least in the short term, patterns of segregation mediate the gender impacts of technological upgrading and automation instead of leading to equalization in terms of the gender composition of the workforce across operations. For instance, the automation of cutting operations decreases the need for both specialized skills and physical strength, yet the operation remains male-dominated. Similarly, the semi-automation of sewing (with automation of suboperations) did not change the gender composition of workers, and the activity remains feminized. In the medium to long term, technological advances linked with changes in skills and physical strength requirements, the availability of training, and a tendency towards multiskilling and multitasking, coupled with the limited availability of workers, could contribute to breaking patterns of gender segregation. Effective change might, however, necessitate greater social change regarding cultural norms and stereotypes which underpin the current gender division of labour. To date, gender equality represents social desirability rather than reality.

Conclusion

We set out to investigate how technological upgrading and automation are impacting women's and men's employment in the apparel and footwear industries in Germany, Indonesia, Mexico, Romania, and Spain. The apparel and footwear industries have played a central role in industrialization processes, providing a source of formal employment opportunities in developing countries, particularly for women. We have considered whether automation might undermine the decent work opportunities historically provided by the sector, and whether women and men may be impacted differently. A critical issue concerns the potential defeminization of the workforce which literature suggests often accompanies increases in capital intensity and productivity (Kucera and Tejani 2014; Tejani and Kucera 2021). Aiming at effectively understanding what is happening at the firm level, we adopted a qualitative approach with in-depth case studies of 14 factories across the research countries, including 125 interviews with managers and workers.

The case studies' findings suggest that there are significant barriers to automation in the industry, chief among which are technical bottlenecks and costs. Technological upgrades are gradual and fragmented, and driven by demand for high and consistent quality, productivity, and efficiency, in the context of great international competition and a limited supply of specialized labour.

We have outlined the following results in terms of gender. Thus far, labour-savings impacts have been more than compensated by growing demand and production expansion. As such, we did not identify defeminization processes, defined as women being disproportionately dismissed relative to men at the factory level, at least in the short-term. In fact, some of the operations which have seen most automation have historically been male dominated, such as cutting. It is important to note that this does not preclude defeminization at the sectoral level. For instance, factories that are born automated may have a different gender composition of labour with implications for the sectoral level. Assessing change at the sectoral level was outside the scope of this research project and merits future research.

Findings on gender indicate that horizontal and vertical segregation has persisted, and that women and men continue to be concentrated in operations which have been traditionally marked by their presence, in what we termed a legacy or carry-over effect, at least in the short-term. This appears to be linked to a certain path dependency on the historical gender division of labour, which stems from ingrained cultural norms and gender stereotypes that attribute certain characteristics and tasks to women and to men. Wages of neither women nor men appear to have been directly impacted by technological upgrading. We also found that automation led to changes in job requirements, including skills and physical strength, which have been combined with a tendency towards multiskilling and multitasking for a more adaptable workforce. These shifts could eventually lead to shifts in the gender

division of labour, weaking segregation, but we know neither the pace nor the strength of these eventual impacts.

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4. General conclusions

Marta Fana

The relationship between automation, employment and the future of work has always been central within the academic and policy debates, and recent years were not an exception. The present project contributes to these debates by means of qualitative case studies at the establishment level across five countries (Germany, Indonesia, Mexico, Romania and Spain) and two economic sectors (automotive and apparel and footwear). The two sectors can be considered as opposite extremes in terms of automation adoption, with the apparel and footwear sector characterized by a low level of automation compared to the automotive sector with a high level of automation. In other words, the apparel and footwear sector remains highly labour-intensive compared to the automotive sector, which is instead very capital-intensive. Additionally, the two sectors are characterized by a different gender composition of the workforce: the apparel and footwear sector is female-dominated while the automotive sector is male-dominated. The countries under investigation were selected for their heterogeneity in terms of national institutions, their position along the value chains of the two sectors studied, as well as their centrality with respect to regional and global markets. Unfortunately, difficulties in visiting the establishments and carrying out the face-to-face interviews undermined, to some extent, the outcomes of the study, including due to long wave of COVID-19 restrictions and following reorganisation as well as restructuring due to energy crisis. In particular, it should be recalled that factory visits were not possible in the German automotive sector, and that therefore information was gathered through interviews with industry experts. At the same time, in some cases, it was not possible to interview workers because of both management of trade unions not agreeing to this.

Despite these difficulties and challenges, the research setting provided the ground to explore different layers of heterogeneity and to take stock of similarities that emerged through the field interviews with workers employed in different occupations and stage of production involved and impacted, although to different extents, by the deployment of automation technologies within the establishments.

Before summing up the main findings of the case studies, it is worth stressing that the qualitative approach based on in-depth case studies built upon semi-structured interviews does not allow us to generalise the findings to the economy-wide level. Yet, the qualitative approach and richness of raw materials allows us to explore nuances of the ongoing production and labour process impacts of recent adoption of automation technologies, and technological upgrading more generally, at the plant level.

The case studies confirm that automation in both sectors has been an incremental process, with full automation not yet in sight. Especially within the automotive sector, during the last two decades no new wave of automation emerged. Moreover, recently, technological upgrade is mostly shaped by the introduction of digital technologies aimed at complementing existing automation technologies. In the apparel and footwear industry, significant technical bottlenecks to automation persist and labour-intensity remains high. Nevertheless, remarkable advances in automation were observed, particularly in the production of knitted apparel.

In both the automotive and apparel and footwear sectors, the deployment of automation technologies is driven by the need for enhanced output quality, greater efficiency, and, most importantly, higher productivity. While all these reasons apply regardless of the specific factory case, it is worth highlighting that for suppliers of automotive components, the need for zero errors plays a pivotal role in achieving efficiency of the production process whose outputs are sold to final assemblers. On the other hand, financial considerations and budgetary restraints play a significant role in the decision to adopt automation technologies in both sectors. Furthermore, workforce related issues should be considered as drivers of automation when it comes to the apparel and footwear sector. Indeed, the limited availability of skilled workers has incentivized technological upgrades in several of the studied cases. High or increasing labour costs have also contributed to the push towards automation, but did not appear as the sole or main cause for it.

The two sectors also face similar barriers to technological upgrading, including technological limitations, costs associated with equipment purchase and maintenance, worker training, and idle time. However, the apparel and footwear sector faces specific challenges due to the pliability of fabrics, the variety of patterns and sizes and constantly changing products, making automated sewing and other production processes more difficult.

We turn now to summarising main findings related to the main objective of the project, that is employment and labour impact of automation deployment and their gender dimensions. While automation technologies have not immediately led to employment displacement in either sector, the automotive sector has experienced reduced employment over time through retirement plans and limited new hirings. In the medium and long run, employment reduction due to technological upgrading could emerge, although this is often mitigated by increases in volumes produced. From the firm perspective, the productivity enhancing goal seems to be reached.

However, in the short term, close to the introduction of new automation technology, the impact on employment takes the form of reassignment of workers directly involved in automated processes to other positions, tasks, and occupations. This leads to a change in the composition of the workforce due to automation and technological advancements with a pivotal role played by maintenance workers. 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. The relocation of workers towards different occupations within the plant has some implications for gender segregation. Indeed, although both sectors remain highly segregated, with the apparel and footwear being female-dominated, while the opposite applies to the automotive sector, the automation of repetitive and heavy tasks has enabled the automotive sector to hire more female workers as line operators, according to some of the interviews. In the apparel and footwear sector, historical patterns persist – sewing and finishing tasks are still predominantly done by women, while cutting and knitting tasks are predominantly done by men. However, new technologies, with lower skills and physical requirements coupled with a tendency to multiskilled workers, undermine the purported reasons given by respondents for patterns of gender segregation in the sector. Moreover, according to the interviews, in the apparel and footwear sector new jobs were created to monitor and programme machinery, as well as to operate specialized equipment and software. In line with expectations, these new jobs involve more likely engineers and maintenance workers whose share over total employment will likely increase in the future, and these positions have historically been more associated with male employment. However, their work may be different from what was until now. In fact, it can be expected that while their duties will be mostly related to analytical and problem-solving tasks, they will be subject to less autonomy and more standardisation than before. This is especially true if they will be hired as technical professionals dealing with the processing of data flows for management's sake.

Furthermore, the relocation of work entails reskilling processes which do not necessarily involve specific training related to the new technology since it depends on the tasks and occupations workers are asked to perform (the workers affected by the new technologies may not need to directly operate them). At the same time, training related to the use of new technologies is foreseen for workers operating new machinery, and for pivotal figures like maintenance workers, engineers and middle management in both sectors. It is worth emphasising that the governance of the training programmes is quite heterogeneous across countries and sectors. In some cases, training is developed and provided internally, in other cases it is administered by the suppliers of the technologies, while in some other cases it is done by the leading company.

Besides these findings in terms of employment displacement and relocation, this study also explored the impact of automation in terms of work organisation and working conditions.

Across the case studies, it emerged that the adoption of automation technologies has reduced heavy and repetitive tasks and improved health and safety for workers directly concerned by automation.

However, at least in the automotive sector, better health and safety conditions only concern the physical aspect, like ergonomics, while mental health risks emerged in some cases because of increased work intensity, i.e., pace of work and saturation time. Another interesting and related common finding is the reduction of workers' autonomy who are now subject to more standardisation of tasks together with an ongoing process of deskilling of operators. Deskilling can be linked to lower specialized skills requirements for certain production jobs (e.g., workers in cutting in the apparel and footwear industry), as well as to the deployment of digital technologies which concentrate intellectual tasks at the top and middle management level. Moreover, digital monitoring of workers' performances also increases establishments' capacity to exercise indirect control and therefore reduce workers autonomy. However, the huge amount of information provided by digital technologies is not always analysed and therefore used at its potential. As it emerged from the interviews, barriers to exploit the data and information flow enabled by digital technologies are mostly based on economic considerations which apply to the short-term perspective. In fact, analysing data is firstly an investment in terms of infrastructure and labour. At the same time, a strategy on how to manage that information requires an upgrade also in terms of management strategies and culture.

The deterioration of workers' autonomy because of new indirect forms of controls and the high degree of standardisation induced by automation can also lead to the (re)emergence of classical forms of alienation. For instance, as reported by a worker in the apparel sector, this way of organising work allows her not to think how to do the job but just to mechanically follow instructions.

Finally gender segregation at the task level persists in both sectors despite technological advancements. Indeed, in the apparel and footwear sector, we did not find evidence of defeminization at the establishment level as well as the automotive factories remains highly male-dominated. Overall, in apparel and footwear, the workforce of the establishments studied remains feminized and while there are examples of women engaging in tasks traditionally performed by men, change has been limited and slow. Cultural norms and stereotypes which influence not only the jobs women and men apply to and get hired for, but also which training and education they engage in, contribute to this gender segregation in both sectors. While there have been limited changes in the gender composition of the workforce in the factories selected for case study, re-composition of employment needs to be analysed with an intersectional perspective due to the increasing role of migrant workers, especially in the European apparel and footwear sector. Despite efforts at the establishment level, breaking patterns of gender segregation requires social change regarding cultural norms and stereotypes in both sectors.

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