UNIVERSITÀ DEGLI STUDI
DI MODENA E REGGIO EMILIA

Dottorato di ricerca in Lavoro, Sviluppo e Innovazione

Ciclo XXXVI

Skilling the automotive sector: juggling between traditions, shocks and innovations

Candidato: Giuseppe Caruso

Relatore: Prof. Giovanni Solinas

Correlatore: Prof. Fabrizio Patriarca

Coordinatrice del Corso di Dottorato: Prof.ssa Ylenia Curzi

L'Etica è qualcosa di cui l'economista deve tener conto. Ogni tentativo di costruire un'economia astratta è destinato a fallire. - Alfred Marshall

Ringraziamenti

Al termine di un percorso intenso, che mi ha dato tanto, non posso che esprimere la mia soddisfazione ed il mio impegno a ripartire da qui. Voglio ringraziare e condividere il risultato, innanzitutto, con il prof. Giovanni Solinas per il costante aiuto e per la dedizione dimostrata nei miei confronti in questi anni.

Ringrazio il prof. Fabrizio Patriarca per avermi insegnato tanto di econometria ed aver spesso creduto in me, fin dalla mia tesi magistrale.

Ringrazio i referenti esterni della tesi, la prof.ssa Annalisa Caloffi ed il prof. Giuseppe Pignataro per gli utili consigli che mi hanno dato.

Ringrazio mio padre e mia madre che mi hanno sempre permesso di inseguire i miei sogni.

Ringrazio i miei nonni, i miei zii e tutta la mia famiglia nel suo senso più ampio che mi permette di riscoprire i veri valori della vita.

Ringrazio mio fratello che mi sopporta, soprattutto nelle giornate più grigie.

Ringrazio Elena che invece mi supporta, soprattutto nelle giornate più intense.

Ringrazio di vero cuore i miei amici della Sacra Famiglia. Ringrazio Simone, Antonio, Gianluca, Luca e tutte le persone sulle quali posso sempre contare. Ringrazio da ultimo, non per importanza, tutti i miei colleghi del dottorato.

Ma soprattutto ringrazio i miei studi economici perché mi danno ogni giorno tanto. Ringrazio Nash, Marshall, Simon, Keynes, Von Hayen e tutte quelle geniali menti che mi hanno insegnato fin dal primo giorno di studi tutta l'Etica che l'economia ha. Ogni studio economico parla di persone, di ambiente, di vita e questo un'economista non deve mai dimenticarlo. Ho sempre creduto nei numeri. Ma credo che sia soltanto nelle infinite equazioni dell'amore (nel senso greco del termine, φιλία, che è il più ampio possibile) che si può trovare ogni ragione logica.

CONTENTS

Summary

The automotive industry is undergoing profound changes that are fundamentally reshaping the global supply chain. New companies are emerging to face environmental, economic, and social challenges. Due to the complexity of these dynamics, this study does not provide a detailed analysis of the entire structure of the automotive industry. The global final production structure of the automotive sector is complex, with a production capacity of around 83 million vehicles per year. The industry relies heavily on a dense network of small and medium-sized enterprises (SMEs) that supply key components for car production. This thesis aims to analyze the global production structure using complex network analysis and underscore the impact of ongoing transformation processes on labour and skill demand. The formation of specifically trained human capital plays a central role in determining the sustainability of the production chain and the economic future of entire production areas. The first chapter examine the structure of global automotive value chains through network analysis, exploring the economic areas involved in the production process and defining the role played by major global manufacturers within the production chain. The analysis was conducted using data from Bloomberg. The data allowed the identification of 3,323 companies that had 11,182 business relationships between 2018 and 2020. The second chapter is based on the results of the first paper and looks at certain aspects of the supply chains of ten well-known OEMs: General Motors, Ford, Volkswagen, Stellantis, Renault, Toyota, Hyundai, Kia, BYD, and Great Wall. We have a total of 343 key suppliers which are part of the supply chains of these ten brands. The analysis shows that these key suppliers could generate more annual revenue than the manufacturers. As a result, the automotive supply chain has become more concentrated with the emergence of large global suppliers. The subsequent chapters focuses specifically on the Emilia-Romagna region, identifying the main determinants of employment in the automotive sector, with a particular focus on the evolution of skills required by workers over the analyzed period. The third chapter investigates the evolution of skill demand within the sector, identifying occupations currently in high demand and those in decline due to ongoing technological innovation processes in Emilia-Romagna. This analysis aims to provide a tool for identifying training needs within the regional sector. The fourth chapter analyses the correlation between education and employment in the metalworking industry to determine the skills that tertiary education can provide to engineers entering the industry. Universities can play a crucial role in training human capital to help companies to face the process of digitalisation and innovation that the sector has now embarked upon globally.

Sommario

L'industria automotive sta attraversando un periodo di profondi cambiamenti interni che stanno radicalmente trasformando la struttura della filiera produttiva globale con l'ingresso di nuovi ed influenti player capaci di affrontare le principali sfide ambientali, economiche e sociali. Dati i complessi meccanismi in gioco, analizzare in maniera esauriente l'intera struttura dell'industria automotive è al di fuori della portata di questo studio. Dal lato della produzione finale, il settore automobilistico dispone di una complessa struttura articolata su scala globale e capace di produrre circa 83 milioni di autoveicoli su base annua. La filiera produttiva si fonda su una fitta rete di piccole e medie imprese che fornisce componenti chiave per la produzione di automobili e che è oggi fortemente influenzata dagli enormi cambiamenti che stanno modificando radicalmente il settore con il diffondersi di processi innovativi, come l'elettrificazione dei veicoli, e con la trasformazione del contesto sociopolitico ed il ruolo crescente giocato dai mercati emergenti. L'obiettivo della tesi è di esaminare alcuni aspetti della struttura produttiva mondiale attraverso una complessa analisi di rete, sottolineando alcuni degli effetti dei processi di trasformazione in atto sulla domanda di lavoro e di competenze. Dalla formazione di capitale umano specificatamente formato deriva la sostenibilità della catena produttiva ed il futuro economico di intere aree produttive, che hanno in passato giocato un ruolo fondamentale nel processo di produzione degli autoveicoli.

Il primo capitolo della tesi si propone attraverso l'analisi di network di esaminare la struttura delle catene globali del valore per il settore automotive. In questo senso, lo studio indaga le aree economiche principalmente coinvolte nel processo produttivo e definisce il ruolo che i principali produttori globali svolgono all'interno della filiera produttiva. L'analisi è stata condotta utilizzando i dati di fonte Bloomberg. I dati hanno permesso di identificare 3.323 aziende che hanno generato 11.182 relazioni commerciali tra il 2018 e il 2020.

Partendo dai risultati del primo paper, il secondo capitolo analizza poi alcuni specifici aspetti delle catene di fornitura di dieci noti OEM: General Motors, Ford, Volkswagen, Stellantis, Renault, Toyota, Hyundai, Kia, BYD e Great Wall. L'analisi individua 343 fornitori chiave che fanno parte delle catene di fornitura di questi dieci marchi. Questi fornitori chiave potrebbero generare in alcuni casi un fatturato annuo superiore a quello dei produttori finali. Di conseguenza, la catena di fornitura automobilistica è diventata più concentrata con l'emergere di grandi fornitori globali.

I due capitoli successivi si focalizzano sul settore automobilistico della regione Emilia-Romagna, centrale per l'economia dell'intero territorio. L'obiettivo di questa seconda parte

della tesi è indagare l’evoluzione delle competenze richieste ai lavoratori assunti nel settore nel tempo. In particolare, attraverso l'utilizzo e l'analisi delle comunicazioni obbligatorie dell’Emilia-Romagna, il terzo capitolo identifica le occupazioni che sono oggi più richieste nel settore automotive locale e quelle con un trend negativo per via dei processi di innovazione tecnologica in atto. Il fine dell'analisi è costruire uno strumento utile a identificare i fabbisogni formativi del settore a livello regionale. In questo senso, il quarto capitolo esamina il rapporto tra istruzione ed occupazione all'interno dell'industria metalmeccanica, utilizzando i dati amministrativi dell’Università di Modena e Reggio Emilia ed i dati di fonte Almalaurea. L'obiettivo del capitolo finale è identificare e definire le competenze che l'istruzione terziaria può fornire agli ingegneri che entrano nel settore. La formazione di capitale umano attraverso la formazione universitaria può rappresentare un elemento fondamentale per le imprese per affrontare il processo di digitalizzazione e di innovazione che il settore ha ormai intrapreso a livello globale.

Introduction

The automotive industry is undergoing profound changes that are fundamentally reshaping the global supply chain. New companies are emerging to face environmental, economic and social challenges. Due to the complexity of these dynamics, this study does not provide a detailed analysis of the entire structure of the automotive industry. The global final production structure of the automotive sector is complex, with a production capacity of around 83 million vehicles per year. The industry relies heavily on a dense network of small and medium-sized enterprises (SMEs) that supply key components for car production. These companies are currently facing significant challenges due to the disruptive changes that are redefining the sector, such as the increase in importance of emerging markets and the rise of electrification (Humphrey and Memedovic, 2003; Sala and Pregnolato, 2022). This thesis aims to analyze the global production structure using network analysis and underscore the impact of ongoing transformation processes on labour and skill demand.

The first chapter examines the structure of the global automotive supply chain in the period 2018-2020 using network analysis. The analysis aims to identify key manufacturers and countries involved in production activities. The analysis is based on data from Bloomberg, allowing us to identify 3,323 companies with 11,182 business relationships between 2018 and 2020. The second chapter extends the findings of the first paper, looking at specific aspects of the supply chains of ten major OEMs (General Motors, Ford, Volkswagen, Stellantis, Renault, Toyota, Hyundai, Kia, BYD, and Great Wall). We have a total of 343 key suppliers in their supply chains. According to the analysis, these key suppliers have the potential to generate more annual revenue than the manufacturers themselves. Automotive supply chains are becoming more concentrated, with large global suppliers emerging.

The subsequent chapters focuses specifically on the Emilia-Romagna region, identifying the main determinants of employment in the automotive sector, with a particular focus on the evolution of skills required by workers over the analyzed period. The region has a strategic position in the supply chain of the automotive industry due to the presence of major luxury brands and a dense network of micro and small enterprises. Local companies need to invest in resources and skills to understand the processes of digitalisation and electrification. The third chapter examines the evolution of skills demand in the sector, identifying occupations that are currently in high demand and those that are in decline due to the ongoing technological innovation processes in Emilia-Romagna. The fourth chapter analyses the correlation between education and employment in the metalworking industry to determine the skills that tertiary education can provide to engineers entering the industry. This introduction aims to provide a brief overview of developments in the automotive industry over the last few decades. It will highlight some of the key issues that will be explored throughout the thesis.

The automotive industry has historically focused on final production. In 2018, the top 20 OEMs employed 75% of workers in the sector and produced around 88% of the vehicles registered worldwide (Hoeft, 2020). The development of a sophisticated exchange system has been facilitated by advances in communication technologies and a gradual reduction in transportation costs (Simonazzi et al., 2022). Since the 1990s, globalisation has had a significant impact on the car industry. Peripheral governments offer tax incentives and wage cuts to attract major OEMs, encouraging them to sign trade agreements and benefit from their proximity to global markets (Baldwin, 2000; Ernst and Kim, 2002; Frigant and Lung, 2002; Gereffi et al., 2005). This trend highlights changes in production factor costs and trade flows in emerging economies. These have increased global demand for cars following market saturation in the West (Harvey, 2014).

The sector has become highly globalised, divided into macro-regions: North America (US, Mexico and Canada); Europe (Germany, Southern and Eastern Europe and the US); Asia (Japan, China, South Korea and East Asia); and South America (Brazil and Argentina). This has profoundly transformed the dynamics of the global supply chain (Sturgeon et al., 2008; Pavlínek, 2018). The financial crisis of 2008 was a critical moment for the automotive industry. In the NAFTA region, production fell from 12.9 million to 8.7 million vehicles. This represents a significant decline of 32.4 percent. US companies took advantage of trade agreements and tariff benefits and shifted a significant part of their production to Mexico (Contreras et al., 2012; Dussel Peters and Gallagher, 2013). The European car industry also faced saturation in Western markets. As a result, they started a process of economic consolidation, characterised by a complex system of mergers, acquisitions and alliances.

China's role in the international context has been expanding. Similar to Japan and Korea, China imported significant technology from overseas and has developed a domestic industry with a brand name. Additionally, the Chinese government has maintained strict control over the economy by limiting imports and promoting joint ventures and competition between domestic and foreign producers. The objective is to prevent foreign entities from colonising the Chinese market, as has happened in Mexico, Brazil and Argentina. The rise of electric vehicles and the increasing importance of in-vehicle technology have had a significant impact on China's market share in the automotive industry.

Following a period of relative inactivity, the major OEMs has begun investing heavily in electric vehicles in response to the extraordinary growth in global demand (Lampón et al., 2017; Alochet et al., 2021; Russo et al., 2022). The transition to EVs and its impact on the global production chain are closely linked to electric battery manufacturing, which is overwhelmingly dominated by East Asia (Gruss and ten Brink, 2016). According to Brown et al. (2021), China is projected to account for 77% of global production by 2021. China's dominant position in the electric car industry is a result of its long-term investment (Yeung, 2019; Yeung and Liu, 2023). The Covid-19 pandemic has led to an increasing industrial dependence on China. Western countries are forming joint ventures with Chinese start-ups to duplicate new powertrain technologies in their factories in order to catch up with China's market dominance (Heim et al, 2021; Wang et al, 2021; Russo et al., 2021). This is aimed at restricting Chinese potential to start exporting EVs globally. This shift could gradually reduce the economic importance of the traditional OEMs.

In a complex geopolitical context, the pandemic has significantly impacted the production process of the industry (Baumgarter et al., 2020). Despite a significant recovery, automotive production levels have not yet returned to pre-pandemic levels and the future of the industry remains highly uncertain. After reaching 96.2 million in 2017, the sector experienced a sharp decline in global sales following the outbreak of the pandemic, falling to 78.7 million in 2020. Between 2020 and 2021, the market experienced a growth of 5.1%. A significant share of this growth was attributed to the surge in demand from the BRICS nations (Brazil, Russia, India, South Africa, and China). The production of cars in BRICS countries increased from 29.8 million in 2012 to 33.9 million in 2021. In 2018 and 2019, BRICS countries sold 36.8 million cars (Osservatorio della componentistica automotive italiana, 2022). Between 2012 and 2021, demand in NAFTA, Western Europe, and Japan decreased from 35.3 million units to 34.2 million units. The largest decline occurs between 2019 and 2020, when sales fall from 41.2 million to 33.7 million units, a 22.2% drop. Since the 2008 financial crisis, the Western market has become saturated, leading to a growing investment in emerging markets. As a result, these markets now have a considerable impact on the sector's market demand. The market share gap between the Western world and the emerging BRICs, which was significant at the end of 2012 (42.9% versus 36.3%), has now disappeared. Currently, both regions play similar roles in international markets.

Summarising the current context of the automotive sector and highlighting the key elements is a complex task. The introduction of innovative driving technologies that promote increased connectivity and electric driving has significantly changed the traditional form of the motor vehicle. The automobile, once perceived as a purely mechanistic device, is undergoing a remarkable shift. These alterations have affected the entire production process, introducing skills that were once irrelevant to the automotive sector. The industry is also currently facing several unresolved issues and challenges, such as:

- Structural overcapacity, with approximately 40% of production facilities remaining unused (Veloso, 2000; Veloso et al., 2002; Arthapan, 2019);
- Extremely high costs related to the development of new products and platforms;
- Emissions regulations becoming increasingly stringent (Hooftman et al., 2018)
- Unprecedented advancements in technology, resulting in elevated costs per year for electrification and for automation. The leading companies invested over twice as much in research and development (R&D) compared to the conventional manufacturing sector, accounting for just under 6% of revenues. In comparison, the Healthcare sector, which heavily relies on research, spent 16% of its revenues on R&D (Pavlínek, 2012);
- Since the 1970s, three-quarters of automotive manufacturing can be attributed to plant deverticalization and modularization through the component supply chain (Coffman et al., 2019);
- Highly variable labour costs are evident among Asian manufacturers who have turned to subcontracting in satellite nations such as Vietnam and Cambodia since the 1980s (Veloso and Kumar, 2002).

The thesis examines some of these issues in detail in its four chapters. Additional research on the challenge of the automotive industry can be found in the extensive literature cited in this introduction.

References

Alochet, M., Midler, C., Shou, Y., and Wang, X. (2021). The road to autonomous mobility services: who drives the transition, where, and how?. *International Journal of Automotive Technology and Management, 21*(4), 343-364.

Arthapan, M. (2019). Global capacity still running ahead of production. *LMC Automotive*.

Baldwin, C. Y., and Clark, K. B. (2000). Design rules: The power of modularity. MIT press.

Baumgartner, T., Malik, Y., and Padhi, A. (2020). Reimagining industrial supply chains. McKinsey and Company.

Brown, D., Flickenschild, M., Mazzi, C., Gasparotti, A., Panagiotidou, Z., Dingemanse, J., and Bratzel, S. (2021). The future of the EU automotive sector. Publication for the

Committee on Industry, Research and Energy, Policy Department for Economic, Scientific and Quality of Life Policies, European Parliament, Luxembourg.

Coffman, J., Ganguli, N., Brown, B., and Iyer, R. (2019). Caution ahead-transformation and disruption for automotive suppliers. Deloitte Touche Tohmatsu Limited.

Contreras OF, Carrillo J, Alonso J (2012) Local entrepreneurship within global value chains: A case study in the Mexican automotive industry. *World Development*, *40,* 1013–1023.

Dussel Peters, E., Gallagher, K. P. (2013), NAFTA's uninvited guest: China and the disintegration of North American trade. *Cepal Review, 110.*

Ernst, D., and Kim, L. (2002). Global production networks, knowledge diffusion, and local capability formation. *Research Policy, 31*(8-9), 1417-1429.

Frigant, V., and Lung, Y. (2002). Geographical proximity and supplying relationships in modular production. *International Journal of Urban and Regional Research, 26*(4), 742-755.

Gereffi, G., Humphrey, J., and Sturgeon, T. (2005). The governance of global value chains. *Review of international political economy, 12*(1), 78-104.

Gruss, L., and ten Brink, T. (2016). The Development of the Chinese photovoltaic industry: an advancing role for the central state?. *Journal of Contemporary China, 25*(99), 453-466.

Harvey, D. (2014). Seventeen contradictions and the end of capitalism. Oxford University Press, USA.

Heim, S., Kakitani, K., Lee, J., Shioji, H. (2021). The competition patterns and dynamics of the Chinese Li-Ion battery industry. Gerpisa. Online Seminar.

Hoeft, F. (2020). Assessing organisational capabilities of incumbent car manufacturers in light of current influencing factors. In Gerpisa Colloquium. Paris.

Hooftman, N., Messagie, M., Van Mierlo, J., and Coosemans, T. (2018). A review of the European passenger car regulations–Real driving emissions vs local air quality. *Renewable and Sustainable Energy Reviews, 86*, 1-21.

Humphrey, J., and Memedovic, O. (2003). The global automotive industry value chain: What prospects for upgrading by developing countries. UNIDO Sectorial Studies Series Working Paper.

Lampón, J. F., Cabanelas, P., and Frigant, V. (2017). The new automobile modular platforms: from the product architecture to the manufacturing network approach.

Pavlínek, P. (2012). The internationalization of corporate R&D and the automotive industry R&D of East-Central Europe. *Economic Geography, 88*(3), 279-310.

Pavlínek, P. (2020). Restructuring and internationalization of the European automotive industry. *Journal of Economic Geography, 20*(2), 509-541.

Russo, M., Alboni, F., Carreto- Sanginés, J., De Domenico, M., Mangioni, G., Righi S., Simonazzi, A. (2021). *Mapping specialisations in the automotive international trade: A multilayer network analysis*. Institute for New Economic Thinking Working Paper Series.

Russo, M., Alboni, F., Bonifati, G., Carreto-Sanginés, J., Pavone, P., and Simonazzi, A. (2022). Agents and artefacts in the emerging electric vehicle space. *International Journal of Automotive Technology and Management, 22*(2), 150-177.

Sala, M., Pregnolato, E. (2022). Osservatorio sulla componentistica automotive italiana 2022. ANFIA, Torino.

Simonazzi, A., Carreto Sanginés, J., and Russo, M. (2022). The world to come: Key challenges for the automotive industry. *Economia e Lavoro, 57*(1), 7-23.

Sturgeon, T., Van Biesebroeck, J., and Gereffi, G. (2008). Value chains, networks and clusters: Reframing the global automotive industry. *Journal of Economic Geography, 8*(3), 297-321.

Veloso, F. (2000). The automotive supply chain organization: Global Trends and Perspectives. *Massachusetts Institute of Technology Working Paper*.

Veloso, F., and Kumar, R. (2002). The automotive supply chain: Global trends and Asian perspectives.

Wang, X., Wei, Z. (2021). The battery industry in China. Gerpisa. Online Seminar.

Yeung, G. (2019). 'Made in China 2025': the development of a new energy vehicle industry in China. *Area Development and Policy, 4*(1), 39-59.

Yeung, G., and Liu, Y. (2023). Hybrid governance of joint ventures in transitional economies: The case of Guangzhou Automobile Group in China. *Review of International Political Economy, 30*(3), 1177-1201.

Chapter 1

The global structure of the automotive industry: a network-based view

Elisa Flori, Caruso Giuseppe, Francesco Pattarin and Giovanni Solinas

1 Introduction

Since their emergence in the mid-1980s, global value chains (GVCs) have played an increasingly central role in international trade. Opportunities to achieve economies of scale and the development of new communication technologies have made it increasingly convenient to organize GVCs for generating competitive advantages by outsourcing production activities. In this sense, free trade policies implemented by national governments, such as the Uruguay Round in 1993 and China's accession to the World Trade Organization, were crucial. They had significantly reduced international coordination costs and allowed firms to specialize and to develop economies of scale. In some cases, this created collaborations aimed to fostering innovation, in others to the reductions of costs (Sturgeon et al., 2008; Lema et al., 2018; Giovannetti et al., 2020; Giglioli et al., 2021). The automotive industry is a notable example of such trends.

Competition between car manufacturers has become increasingly intense over the last decades. The structural overcapacity of the global automotive industry that became evident in the mid-1990s is perhaps the single most important factor in sharpening competition. Major manufacturers left traditional brand specializations and turned providing a wide range of models to cover all market segments, with a substantial increase in research and development expenditure and a simultaneous attempt to reduce the time-to-market of new products. Thus, flexible production platforms capable of delivering multiple models were introduced. At the same time, lean organizational methods were widely adopted to reduce waste, shorten production time and reduce labor costs. There was also a growing push to locate plants in areas other than the original ones, either to open new markets, or to control those where manufacturers were already established.

In recent years, two further major phenomena have made the life of the global automotive industry even more restless. The first is digitalization, with its effects on the organization of production and the management of information flows. The second concerns the current and expected regulations about the ecological transition and decarbonization. This set of drivers has affected localization processes and the internationalization of the automotive industry and has shaped GVCs.

This article aims to contribute to the literature on GVCs by describing the network configuration of the industry as it stands today, resulting from the trends that have emerged in recent decades and the constraints imposed by increasingly stringent guidelines related to technological change and ecological transition.

Several scholars have recently addressed these issues, mainly using aggregate data about imports and exports. Our contribution is to map a firm-level network of 3,323 companies from 60 countries across 135 industries, representing a significant proportion of automotive GVCs. With as many as 11,182 business relationships, the network generated average annual sales of about USD 27 billion between 2018 and 2020. Furthermore, we focus on ten subnetworks extracted starting from some of the prominent automotive market leaders: General Motors, Ford, Stellantis, Volkswagen, Renault, Toyota, Hyundai, Kia, BYD, and Great Wall. Our aim is to find patterns in the geographical and industrial linkages of the major car manufacturers.

The construction of a worldwide network at the level of individual firms is new to the literature on GVCs. Existing research strands look at the aggregate level of industries in different countries (*e.g.*, Bonadio et al., 2021; Espitia et al., 2021) or at the level of individual firms for a single country (*e.g.*, Barrot and Sauvagnat, 2016; Inoue and Todo, 2020).

The article is structured as follows. Section 2 accounts for the main recent developments in the automotive industry at the global level. Section 3 describes the data we used to reconstruct the automotive GVCs. In section 4, we first examine the architecture of this network, then provide a focus on ten major companies located in different regions. Section 5 concludes.

2 Internationalization and fragmentation of production in the automotive industry

In recent decades, the automotive industry has undergone major changes its structure of production and trade, which has led to a shift towards the globalization of supply chains (Baldwin and López-González, 2015; Timmer et al., 2015). Several studies suggest that today's automotive industry is not fully globalized but neither fully regionalized; indeed, the industry is organized as highly interconnected international clusters of companies as well as around local clusters (Sturgeon et al., 2008; Amighini and Gorgoni, 2014). Since the mid-1980s, there has been a marked trend towards regional integration of production, leading to the creation of assembly plants serving mainly regional markets. However, internationalization has also increased significantly, culminating in the creation of production plants in developing countries. As a result, China, India, and Brazil have become major competitors in this industry (Sturgeon and Florida, 2004).

In each region, there has been a gradual shift in investments towards countries with lower operating costs. In North America, new plants have been built Southern United States and Mexico, while in Europe capital has been directed towards Spain and Eastern Europe. Similarly, in Asia there has been a significant shift of production to China and Southeast Asia. Examples of such shifts are the activities of Ford, GM, and Chrysler in Mexico, as well as the presence of Volkswagen and Peugeot in Eastern Europe. On the other hand, Western economies continue to be a large market and, therefore, a magnet for Asian manufacturers. Perhaps the clearest example of this is the choice of Japanese major car makers to invest in Europe and in the United States (Sturgeon and Van Biesebroeck, 2010).

2.1 North and Latin America

Over the past few decades, the North American automotive industry has been shaped by three significant factors. First, the large investments made in the USA by Japan, particularly Toyota; second, the growing importance of Mexico following the creation of NAFTA; finally, the closure of several plants as a result of the 2008 economic crisis.

In the early 1990s, there were more than 250 platforms in the United States and Canada which were used to assemble Japanese cars built since the 1980s. As a result, the USA took protective measures to preserve its domestic industry. The main reason for these measures was the concern about the development of the Japanese economy. The 1981 Voluntary Restraint Agreement raised the cost of exporting Japanese components to the USA, thus pushing the Japanese industry to react by establishing production facilities on the North American soil. Conservative manufacturing companies, such as Toyota, saw an opportunity to expand their economic presence in the USA. Nissan and Honda followed, because they saw the USA market as a potential alternative to challenging Toyota at home (Mair et al., 1988). Japanese companies used the crisis of the Fordist system to launch a long-term investment initiative on the American soil. The arrival of highly efficient and low-cost Japanese automobiles was a major challenge to the USA domestic automotive industry. Furthermore, Japanese manufacturers introduced novel techniques for vehicle assembly and organizational work systems in the USA, the so called “just-in-time” or “lean manufacturing” production process (Hufbauer and Jung, 2021).

The establishment of NAFTA in 1994 increased USA investments in Mexico, mainly because of lower labor costs. Mexico has a rich history of car production by international manufacturers, with Ford being the pioneer with the assembly of Model T in Mexico City in 1925. General Motors (GM) and Chrysler built their first assembly plants in Mexico during the 1930s (Werner and Axe, 1993). Between 1994 and 2016, the production of vehicles in Mexico witnessed a remarkable upswing, surpassing a threefold increase from 1.1 million units to nearly 3.5 million units. Furthermore, Mexico experienced a notable escalation in the export of vehicles, surging from 579,000 units to 2.8 million units during the period (Klier and Rubenstein, 2017).

The 2008 financial crisis prompted US manufacturers to outshore their manufacturing processes, resulting in the closure of plants on both the East and West Coast and the relocation of their production sites from the USA and Canada to Mexico. As a result, NAFTA countries experienced a 32.4% decline in production; the number of vehicles produced fell from 12.9 million to 8.7 million units after the crisis (Simonazzi et al., 2022). Also, USA automakers had to seek bailouts from the government. The crisis lead companies such as BMW, Mercedes-Benz, Kia Motors, Mazda, and Audi to close several plants in the USA heartland and to relocate some to Mexico (Klier and Rubinstein, 2017). Indeed, Mexico was an attractive investment destination due to its low labor costs, geographical proximity to the North American market, and tariff agreements with it. As of 2018, Southern USA and Mexico have taken a central role in the production process of the American continent (Rarou, 2023).

2.2 Western and Eastern Europe

In the period between 1999 and 2019, there was a marked decline in the volume of production in the main regions of Western Europe. This decline coincided with the relocation of production to Eastern and Central Europe. This led to a significant transformation of the automotive industry in Europe (Lung, 2004; Pavlínek, 2018). In fact, out of the 460 new factories constructed within the EU from 2005 to 2016, a staggering 95% (438) were built in Eastern Europe through foreign investment (Pavlínek, 2020). Except for Poland, all UE countries saw an increase in production over the period; the Czech Republic, for example, experienced a threefold increase in car production, while Slovakia and Romania saw increases of about eight to four times respectively (Gaddi and Garbellini, 2021). Similarly, Turkey saw an increase in car production from 221,041 units in 1999 to 982,642 in 2019, or about 4.5 times, prompted by a significant contribution from Korean investments in the region (Moretti and Zirpoli, 2020).

Germany is the main European player in the automotive sector, with Mercedes Benz, BMW, Volkswagen-Audi and, in the high-end segment, Porsche. These manufacturers keep a significant part of their production processes close to the continental market, either in their home country or in other places across Europe. Also, Germany has an important global role in the production of engines, as well as in the coordination of the production of electrical components and spare parts for cars in Eastern Europe, which it exports worldwide (Amighini and Gorgoni, 2014). In this respect, German investments in Eastern Europe are aimed at fostering technologies that facilitate data-driven industrial decisions and ultimately increase the competitiveness and productivity of the domestic industry (Calabrese and Falavigna, 2021; Moro and Virgillito, 2022).

The French automotive industry is mainly led by Renault and PSA; the latter is a multinational company, with American, Italian, and French brands as well as manufacturing facilities established worldwide. Spain has not any domestic manufacturers since 1986, when Volkswagen acquired Seat; however, foreign groups such as Nissan, Renault, Volkswagen, PSA, and Ford have several production plants there, as pointed out by Megyeri et al. (2023). Italy presents a peculiar scenario; its main domestic manufacturer is Fiat, a part of the PSA group, whose importance in the local industry has gradually declined since 2000 because of the out shoring of its production. The Volkswagen-Audi group, through Lamborghini, has some presence in in Italy. This is an example of the recent trend that has shaped the Italian automotive landscape, which is increasingly specializing in high-end luxury and sports cars, with global brands like Ferrari, Maserati, Alfa Romeo (all linked to PSA), Pagani and Dallara.

The significant increase in passenger car production in Central and Eastern Europe is mainly due to foreign manufacturers, especially from Europe and Asia, as shown by Muniz and Belzowsk (2017) and Olejniczak et al. (2020). Volkswagen-Audi, BMW, and Mercedes Benz have established plants in Hungary, Renault has a plant in Romania, PSA, Volkswagen-Audi and FCA are active in Poland, the Czech Republic and Slovakia. Asian carmakers have established plants in Central and Eastern Europe, such as Suzuki in Hungary, Hyundai in the Czech Republic, Kia in Slovakia, and Toyota (in partnership with PSA) in Poland; Ford and Jaguar Land Rover also produce there. Low labour costs and government policies aimed at fostering foreign direct investments are the main factors attracting foreign manufacturers to these countries (Gaddi and Garbellini, 2022).

2.3 Asia

Looking at the automotive industry in Asia means focusing on at least three different economies: Japan, Southern Korea, and China. Although Japan is second to China in terms of the overall production volume in the region, it retains an extraordinarily important role both as a manufacturer of cars and as a producer of parts and components. Japan is fully integrated into the North American production network. Japanese manufacturers (Toyota, Honda, Nissan, Mazda, and Mitsubishi, followed at a distance by Suzuki, Subaru, and Daihatsu) have some 250 facilities, mainly assembly plants, in the USA and Canada, most of them built in the 1980s to circumvent the threat of North American protectionist trade legislation aimed at counteracting the rapid increases of Japanese automobile exports to the region over the 1970s and early 1980s (Mair et al., 1988). Japanese car makers also have plants located in Europe and other Asian countries, such as with China. In these regions, Japanese manufacturers may still enjoy a 'first mover advantage' because of them early adopting lean production processes (Womack et al., 1990; Cole and Yakushiji, 1984). Also, Japan plays an important global role as a supplier of parts, such as electronics, rubber, metal components, and engines. Indeed, Japanese companies have increased their sales to China, are present in the NAFTA, and have a growing role in the coordination and interchange between manufacturers in other Asian countries, the Americas and Europe; their present global importance is unquestionable, and the more so their prominent role in the Asian region (Amighini and Gorgoni, 2014).

The Korean automotive industry comprises five major domestic manufacturers: Hyundai Motor Corporation (HMC), Kia, DMC, Ssangyong, and RSM. The internationalization process of the Korean automotive industry began at the end of 1992, following the election of the liberal-democratic party leader Young-sam Kim as President; by 1996, Korean car sales had reached a total of 2,854,289 units. The 2008 crisis marked a significant turning point for the Korean automotive industry. HMC took over a substantial part of Kia, which had gone bankrupt. Samsung Motors was acquired by Renault to avoid bankruptcy, forming RSM. DMC was bought by General Motors. The Indian company Mahindra and Mahindra took a majority stake in Ssangyong. After such reshaping, the Korean automotive industry entered a new period of expansion. Hyundai and Kia improved their car exports, levering on the production facilities they both established in Turkey, India, and China since the 1990s. Since 2008, Hyundai has moved some of its production to the Czech Republic, Russia, and Brazil, and increased its presence in India, China, and Turkey. Kia has invested in new production facilities abroad since 2009, mainly in the USA, Mexico, and India. DMC shut down several plants in Korea and strengthened its presence in North America (Jacobs, 2023).

China's auto industry, currently the world's largest by share of global sales, has also undergone a significant transformation since the 1990s. In particular, the opening of the Chinese market to foreign automotive companies has been driven by joint ventures between state-owned enterprises and foreign manufacturers from North America, Europe, and Asia (Thun, 2006). China has taken advantage of such partnerships to improve its domestic industry since the early

2000s. More recent examples are the collaborations of Continental with Baidu, Bosch and Alibaba (Lüthje, 2021).1 Such global partnership agreements are forming in the rapidly evolving autonomous vehicle sector, which requires both the expertise of traditional automotive suppliers and of companies specialized in artificial intelligence, robotics, and software. Adopting lean organizational principles has led to progress in production processes; furthermore, Chinese companies incorporated foreign production technologies. This was not just copying foreign standards, but taking what of them China has seen useful to promote its automotive industry, internally and abroad. Thus, Chinese manufacturers like BYD, Geely, and Chery have contributed significantly to the growth of the national industry by expanding their domestic market activity as well as foreign exports; in doing this, they received Government support to establish production plants overseas, contributing to their expansion (Lüthje and Tian, 2015). Chinese companies have emerged as leaders in the production of electric vehicles. This is due to their need to control carbon emissions as their population has shifted towards private mobility. Additionally, these firms envision playing a significant international role in the electric car market. This goal is strongly supported by China's access to the materials that are the essential elements of electric cars, such as metals for making batteries. For instance, CATL has announced its plans to construct a battery plant in Erfurt, Germany, to supply major European manufacturers like Volkswagen and BMW (Wang et al., 2022).

Such regional trends have contributed to shape the global architecture of the automotive GVC. In the following sections, we aim to describe it through by reconstructing the supply chain of the leading global manufacturers of cars, motorcycles, trucks, and heavy-duty vehicles.

3 Data

The dataset consists of 3,323 firms connected by 11,182 main business relationships collected from Bloomberg's supply chain database (Flori et al., 2022).2 We retrieved information about the size of companies, as their average annual sales volume in millions of USD, during fiscal years 2018-2020, the region where they are legally established in, and their industry according to the Morgan Stanley Capital International and Standard and Poor's GICS taxonomy.3

[1] "It is worth noticing that the tremendous increase of trade relationships involving China as a partner are relationships in which China acts as a 'representative', that is importing electrical parts from other Asian countries and exporting to the rest of the world". Amighini and Gorgoni (2014): 936-937.

[2] Bloomberg provides data for major clients and suppliers only, limited to twenty instances on both sides.

[3] Appendix A shows the correspondence of each country to its geographical area.

The data collection procedure began with identifying and retrieving all the world's main manufacturers of cars, motorcycles, trucks, and heavy-duty vehicles provided by Bloomberg. We obtained 165 of these companies, to which we give the attribute 'focal'. Then, we constructed the final dataset as follows: first, identifying and selecting the focal firms' main suppliers and customers; then, identifying and selecting the focal firms' main suppliers and customers; finally, eliminating all companies with any missing value among the variables of interest. Thus, we know which companies are the principal suppliers and customers of the focal companies. So, the analysed dataset represents the network of the automobile supply chain limited to the second order; all focal firms are in the network, as well as the firms that are their suppliers or customers, and those that are their customers or suppliers, provided we have all the variables of interest for each observation.

The database used, whose characteristics have been briefly described, also has limitations that must be made explicit. It only includes 'important' relationships (listed firms) and does not provide an accurate measure of exchanges between producers and suppliers over a defined time interval, either in terms of amounts or in terms of the frequency of exchanges. In terms of network analysis, one could say that it allows us to construct nodes and arcs, but it does not give us the thickness of the latter. It is, however, a non-negligible tool for reconstructing the relationships between final firms and supply chains.

4 Network analysis

In this step, an analysis of the worldwide network recreated with the dataset described in the previous section is firstly conducted. Secondly, a level of detail is added by comparing the corporate subnetworks of some of the world's leading car manufacturers.

4.1 Global automotive supply chain

The 3,323 nodes of the automotive supply chain network are connected by 11,182 arcs. In this case, an 'arc' is a direct connection between two companies, from supplier to customer; that is, if one company sells goods or services to another, then an arc follows and points to the other.

Figure 1 offers a schematic illustration of such a structure, where the circles represent the nodes, and the arrows represent the arcs linking them. The direction of any arc indicates the flow of goods and services between companies.

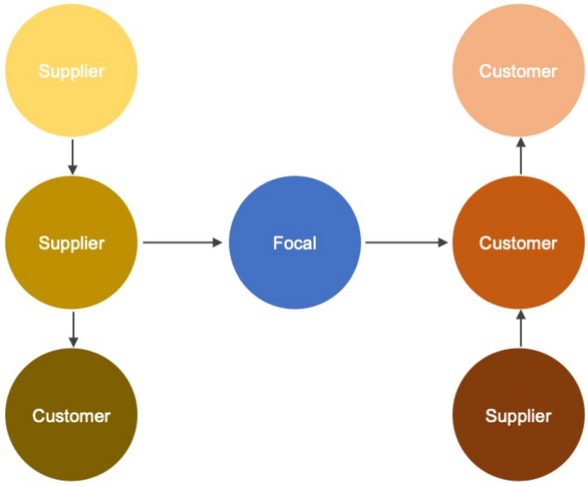


Figure 1. Representation of the second-order automotive supply chain network (Flori et al., 2022).

Thus, some companies are both suppliers and customers (*i.e.*, they have inbound and outbound arcs), some are only suppliers (*i.e.*, they have no inbound arcs), and some are only customers (*i.e.*, they have no outbound arcs). Table 1 describes the presence of each type of company in the network.

Type of node	Absolute frequency	Relative frequency (%)
Supplier and consumer	1,192	35.87
of which: Focal companies	*92*	*2.77*
Only supplier	1,201	36.14
of which: Focal companies	*25*	*0.75*
Only consumer	930	27.99
of which: Focal companies	*48*	*1.44*
Total	3,323	100.00

Table 1. Frequency of global network companies by node typology (Flori et al., 2022).

We note that almost half of the focal companies (73) are ‘pure suppliers’ or ‘pure customers’. Overall, the highest share of companies by type is represented by pure suppliers (1,201 or 36.14%). They are followed, with a small gap, by both supplier and customer companies (1,192 or 35.87%) and, finally, by pure customers (930 or 27.99%). Regarding the number of connections per individual company is concerned, Table 2 summarises the descriptive statistics.

Minimum	1st Quartile	Median	Mean	3rd Quartile	Maximum
1.00	1.00	2.00	6.73	6.00	158.00

Table 2. Statistics on the arc distribution of the global network.

On average, each company in the network is connected to others via 6-7 arcs; however, observing a maximum of 158, we can deduce that a large proportion of companies have only one connection in the network.[4] Table 3 shows the ten companies with the highest number of arcs.

Company	Arcs
Nissan	158
General Motors	156
Toyota	155
Honda	153
Daimler	139
Ford	130
Volkswagen	129
Hyundai	126
Stellantis	125
Denso	107

Table 3. Arcs of global network by single company (top 10).

To obtain a more accurate understanding of the network structure of the automotive supply chain, we report the number of companies and sales volume by geographical location and activity segment in Tables 4 and 5.[5]

Region	Companies	Sales (USD Mln)
China	598	4,912,127
Japan	593	3,986,988
Other Asia	545	1,179,050
North America	512	8,465,809
South Korea	510	1,457,592
Northern Europe	126	2,148,042
India	114	274,042
Germany	66	1,501,269
France	54	1,090,127
Oceania	37	161,277
Central Europe	36	523,776
Eastern Europe and Russia	32	176,201

[4] Appendix B provides a graphical representation of the subnetwork constructed from the lead firms we focus on in the next section, where we distinguish nodes by the number of arcs.

[5] Appendix C shows the relevance of individual geographic areas and business industries focusing on network connections. Specifically, we indicate the number of incoming and outgoing arcs and their sum.

Southern and Western Europe	31	431,097
Latin America	30	250,793
Middle East	28	391,897
Africa	11	17,377
Total	3,323	26,967,464

Table 4. Number of companies and sales volume of the global network by geographic area.

Industry	Companies	Sales (USD Mln)
Electronic components	406	396,599
Auto parts and equipment	304	815,556
Steel	300	1,010,530
Application software	276	168,598
Industrial machinery	122	246,659
Semiconductors	109	374,819
Automobile manufacturers	76	2,407,128
Semiconductor equipment	75	80,235
Distributors	73	197,617
Technology hardware, storage and peripherals	71	1,109,192
Construction machinery and heavy trucks	70	444,236
Construction and engineering	68	851,541
Electric components and equipment	68	189,327
Commodity chemicals	55	274,608
Trucking	55	157,316
Electronic equipment and instruments	53	137,491
Technology distributors	52	239,473
Trading companies and distributors	51	685,386
IT consulting and other services	47	374,306
Communications equipment	43	152,395
Other	949	16,654,449
Total	3,323	26,967,464

Table 5. Number of companies and sales volume of the global network by business industry.

We confirm that Asian countries currently dominate the automotive market, with 2,246 companies accounting for 67.59% of the worldwide network with sales of USD 11,535,757 million. Subsequently, one finds North America (512 companies recording sales of USD 8,465,809 million) and the Eurozone -mainly Northern Europe, Germany, and France (246 companies recording sales of USD 4,739,438 million). Regarding business industry, more than one-third of the companies in the network belong to the top 4, namely ‘Electronic components’, ‘Auto parts and equipment’, ‘Steel’, and ‘Application software’. However, the category that generates the second-highest sales after ‘Automobile manufacturers’ is ‘Technology hardware, storage, and peripherals. The increasing trend of electrification and driving automation is turning cars into services provided to consumers. The companies that supply electrical components and develop vehicle software applications play a central role in this transformation. This trend aligns with the green initiatives that governments have implemented on national and international levels to support sustainability.

Finally, looking at the share of supplier nodes in the total number of nodes involved in the production network (*i.e.*, supply ratio), Table 6 shows that some regions play a more critical role in supplying the international market within the automotive production chain. Germany has a supply ratio value of 59%, meaning that 59% of the total business relations generated by local German firms are supply relations. The figure for Northern Europe is 55%, for China 52%, and for North America 50%.

Region	Out	Tot	Supply ratio
China	1,501	2,882	52.08%
Japan	2,585	5,680	45.51%
Other Asia	1,141	2,073	55.04%
North America	2,232	4,433	50.35%
South Korea	1,384	2,634	52.54%
Northern Europe	509	929	54.79%
India	376	711	52.88%
Germany	601	1,013	59.33%
France	354	682	51.91%
Oceania	55	135	40.74%
Central Europe	142	494	28.74%
Eastern Europe and Russia	85	167	50.90%
Southern and Western Europe	97	261	37.16%
Latin America	71	148	47.97%
Middle East	34	97	35.05%
Africa	15	25	60.00%

Table 6. Supply ratio by geographic area.

4.2 Brand comparison

The previous analyses have only looked at the overall characteristics of the global automotive network, without focusing on individual companies. This section examines some of the most significant vehicles manufacturers by regions, ranked by sales. We consider General Motors and Ford (United States), Stellantis (Northern Europe), Volkswagen (Germany), Renault (France), Toyota (Japan), Hyundai and Kia (South Korea), BYD and Great Wall (China).[6] Table 7 shows the geographical location and sales volume of these companies and the number of arcs connecting them to their direct commercial counterparts, suppliers and customers.

Brand firm	Region	Sales (USD Mln)	In	Out	Tot
General Motors	North America	135,590	145	11	156
Ford	North America	147,794	117	13	130
Volkswagen	Germany	271,953	114	15	129
Stellantis	Northern Europe	116,828	109	16	125
Toyota	Japan	271,045	133	22	155
Hyundai	South Korea	89,031	108	18	126
Renault	France	59,876	84	5	89
Kia	South Korea	49,800	75	14	89
BYD	China	19,441	38	7	45
Great Wall	China	14,644	35	3	38

Table 7. Region, sales volume, and arcs by brand firm.

Inbound arcs are much higher than outbound arcs. This figure is in line with expectations, as we can easily assume that there are more categories of players to whom automotive manufacturers must turn to obtain raw materials and semi-finished products than to whom they must send the finished product. Furthermore, the total number of arcs gives a first indication regarding the role of the brands in the worldwide network. In this sense, it is possible to assess the share occupied by the subnetworks of these companies in the automotive GVC by looking at sales volume and nodes in Table 8.

[6] Although Tesla plays a significant role in the automotive industry, we have not included it due to its small market share on a global level.

Brand subnetwork	Sales (USD Mln)	Sales (%)	Nodes (units)	Nodes (%)
General Motors	1,426,766	5.29	157	4.73
Ford	1,112,369	4.12	131	3.94
Volkswagen	1,330,452	4.93	130	3.91
Stellantis	1,235,921	4.58	125	3.76
Toyota	1,524,228	5.65	149	4.48
Hyundai	1,007,091	3.73	123	3.70
Renault	747,246	2.77	90	2.71
Kia	768,156	2.84	88	2.65
BYD	645,756	2.39	45	1.35
Great Wall	345,089	1.28	39	1.17

Table 8. Sales volume and nodes by brand subnetwork.

Every corporate subnetwork account for a minimum of 1% of the worldwide supply chain both in terms of sales volume and nodes. However, it is important to note that the overall share held by the ten OEMs globally is not the mere sum of the individual shares, as there are overlaps in suppliers and customers between the subnetworks of the major car manufacturers. Altogether, they occupy more than 13.5% and about 10% of the worldwide network in terms of sales volume (over USD 3.6 billion) and nodes (343), respectively. An example of the overlaps can be observed in Figure 2. It examines each pair of subnetworks formed by considering prominent brands of USA, EU, Japan, and China: General Motors, Volkswagen, Toyota, and Great Wall.[7] The plot shows that Great Wall is the most eccentric company; this is also the case of BYD (see, Appendix B).

[7] Appendix D details the overlaps by region and activity segment.

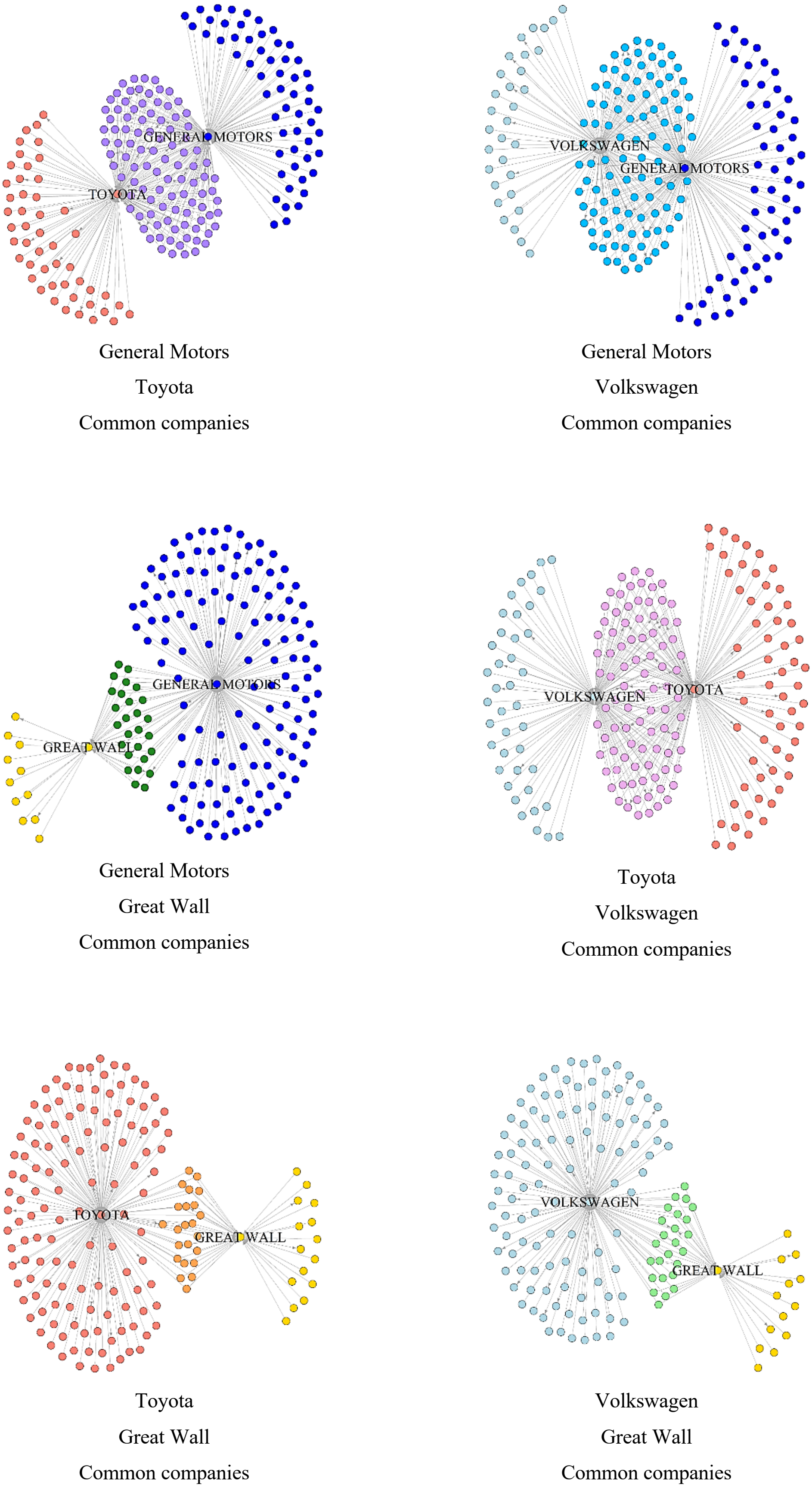


Figure 2. Representation of brand subnetworks overlapping.

Looking at the network of first-tier partners of the ten car manufacturers, Table 9 highlights the prominent role of Asian producers (197 out of 343 companies). It is also worth noting that most of the links are upstream and that there is a significant core of large global suppliers: Korean LG and Posco, Chinese Tianjin Pengling and Japanese Denso supply more than 100 companies. In addition to traditional segments such as tires and steel, these major players are active in fragmented markets with a wide range of products. This is the case for Japan's Panasonic and USA's Arrow Electronics.

Region	North America	Europe	Japan	South Korea	China	Other Asia	Rest of the world	Total	Total (%)
Automotive manufacturers	7	7	1	2	6	5	3	31	9.04
Auto parts and equipment	28	27	65	35	12	5	3	175	51.02
Steel and Aluminium	7	9	6	6	1	0	2	31	9.04
Electronic components and instruments	20	6	8	6	13	4	1	58	16.91
Semiconductors	0	1	0	2	1	0	0	4	1.17
Industrial machinery	1	3	1	3	0	0	0	8	2.33
Tires and rubber	1	1	0	0	1	0	0	3	0.87
Other industries	1	5	0	1	4	0	0	11	3.21
Services	1	3	1	4	1	0	0	10	2.92
Retailers	7	1	2	0	0	1	1	12	3.50
Total	73	63	84	59	39	15	10	343	100.00

Table 9. Number of companies connected to at least one of the ten leading OEMs by geographic area and business industry.

To define similarities in geographical and industrial diversification of the leading OEM's partners, we provide the number of companies by region and business activity for each brand subnetwork in Tables 10 and 11.

Region	*General Motors*	*Toyota*	*Ford*	*Volkswagen*	*Stellantis*	*Hyundai*	*Renault*	*Kia*	*BYD*	*Great Wall*
Africa	0	0	0	1	0	0	0	0	0	0
Central Europe	5	3	7	7	5	2	6	2	2	1
China	7	4	9	5	8	6	4	3	17	7
France	6	6	7	7	8	4	8	4	3	3
Germany	8	5	7	13	6	5	7	2	4	1
India	3	4	3	3	2	3	3	2	0	0
Japan	46	76	30	32	34	19	18	12	0	9
Middle East and Arabia	0	0	1	0	1	0	1	0	0	0
North America	50	33	46	41	41	28	19	21	8	9
Northern Europe	6	7	7	7	7	6	5	5	5	7
Oceania	1	0	0	0	1	1	1	0	0	0
Other Asia	3	6	3	2	3	1	4	0	2	0
Eastern Europe and Russia	1	0	2	2	0	0	2	0	0	0
Latin America	1	1	1	1	1	1	1	1	0	0
Southern and Western Europe	4	4	5	6	5	3	4	1	1	1
South Korea	16	0	3	3	3	44	7	35	3	1
Total	157	149	131	130	125	123	90	88	45	39

Table 10. Number of companies of brand subnetworks by geographic area.

Industry	*General Motors*	*Toyota*	*Ford*	*Volkswagen*	*Stellantis*	*Hyundai*	*Renault*	*Kia*	*BYD*	*Great Wall*
Application software	8	6	6	6	6	7	5	2	1	0
Auto parts and equipment	102	101	84	83	82	84	65	63	11	30
Automobile manufacturers	1	4	4	2	5	2	3	2	1	1
Automotive retail	7	8	7	8	7	7	0	5	0	0
Electronic components	12	7	9	10	5	5	3	1	6	0
Steel	17	13	15	12	12	8	6	5	2	0
Trucking	5	3	4	3	4	3	3	3	0	0
Other	5	7	2	6	4	7	5	7	24	8
Total	157	149	131	130	125	123	90	88	45	39

Table 11. Number of companies of brand subnetworks by business industry.

Hence, despite significant overlaps, we find confirmation that the supply chain organisation is different among the big brands in dimensional, regional, and industrial terms. For example, auto parts manufacturers and steel suppliers are essential in all subnetworks. Still, the role of electrical component manufacturers is more crucial for Ford and General Motors than for the other companies. This can be due to differences in outsourcing production processes. American manufacturers generally follow similar production strategies as the rest of the automotive market. In contrast, Asian manufacturers manage to reduce the length of their supply network by tending to internalise the production of electrical components. Our findings also reinforce the significance of suppliers located in Japan, North America, and Northern Europe for all end manufacturers while acknowledging the increasing influence of developing economies like India and China in conventional supply chains. Additionally, we have validated that companies originating from the US and Europe have established connections with businesses situated in Central Europe.

Finally, we notice that, despite globalization, the automotive industry still has regional dimension. Manufacturers keep a significant share of their production within their home region. Notably, Asians have many partners in their areas. The most significant example is Toyota, with more than 50% of the nodes in its subnetwork located in Japan. Similarly, USA-based Ford and General Motors have over 30% of their production chain in North America. On the other hand, some producers like Stellantis, Volkswagen and Renault operate through several relationships in the European, Asian and North American regions.

5 Conclusions

We use network analysis techniques to provide an updated picture of the automotive industry at the beginning of 2020s on a new granular data set. Five primary characteristics emerge.

First, geographical areas play a significant role in the industry, with China, Japan, and South Korea being the dominant players in Asia, Northern Europe, and America in the West. These countries control 77% of the nodes, with 18% in China, 17.9% in Japan, and 15.3% in South Korea. North America and Europe have 15.4% and 10.4% of the nodes, respectively. These countries generated around 90% of the network's total revenue between 2018 and 2020. However, emerging economies such as India are also becoming increasingly relevant in the production chains. We found 114 Indian companies in the automotive network, representing nearly 4% of the global total, with an average annual turnover of USD 274 million.

Second, the automotive industry maintains a crucial regional dimension. Despite increased internationalization since the 1990s, the industry remains regionally focused, with manufacturers retaining a significant share of their production within their home region. This trend is supported in the academic literature mainly by the persistence of transport and coordination costs (Smith and Florida, 1994; Schlie and Yip, 2000).

Third, in terms of specialization, we show that more than a third of the enterprises in the network is active in the 'Electronic components', 'Auto parts and equipment', 'Steel', and 'Application software' industries. Nevertheless, the industry with the second-highest sales volume after 'Automobile manufacturers' was 'Technology hardware, storage and peripherals. This confirms the centrality of companies that supply electrical components and develop software applications for vehicles as part of the electrification and driving automation that is turning the car into a set of services offered to the consumer. The trend has been rising in recent years, aligning with national and international policies that governments have implemented to support green initiatives. Furthermore, our data indicate that the percentage of arcs with companies operating in digitalization and vehicle electrification is similar across all regions and final carmakers in the supply chain. Specifically, the ten OEMs analyzed have an average of 12 to 13% of arcs with companies active in those industries. Only Kia (5%) and Great Wall (3%) have significantly lower percentages. These companies are, therefore, less likely to integrate digital skills from outside firms.

Fourth, the network analysis of large global producers reveals high upstream and downstream overlap in the production chain. Adding up the number of nodes occupied by the ten subnetworks examined, they account for more than 30% of the total structure. However, this figure significantly drops when we consider overlaps. The clean value is around 10%, which still shows the importance of the sub-sample investigated.

Finally, our findings show that the leading car manufacturers mainly rely on large Asian producers positioned upstream in the automotive industry. Key suppliers include Korean LG and Posco, Chinese Tianjin Pengling, and Japanese Denso.

References

Amighini, A., and Gorgoni, S. (2014). The international reorganization of auto production. *The World Economy, 37*(7), 923-952.

Baldwin, R., and Lopez-Gonzalez, J. (2015). Supply-chain trade: A portrait of global patterns and several testable hypotheses. *The World Economy, 38*(11), 1682-1721.

Barrot, J. N., and Sauvagnat, J. (2016). Input specificity and the propagation of idiosyncratic shocks in production networks. *The Quarterly Journal of Economics, 131(*3), 1543-1592.

Bonadio, B., Huo, Z., Levchenko, A. A., and Pandalai-Nayar, N. (2021). Global supply chains in the pandemic. *Journal of International Economics, 133*, 103534.

Calabrese, G. G., and Falavigna, G. (2022). Does Industry 4.0 improve productivity? Evidence from the Italian automotive supply chain. *International Journal of Automotive Technology and Management, 22*(4), 506-526.

Cole, R. E., and Yakushiji, T. (1984). The American and Japanese auto industries in transition: report of the joint US–Japan automotive study. University of Michigan Press.

Espitia, A., Mattoo, A., Rocha, N., Ruta, M., and Winkler, D. (2022). Pandemic trade: COVID-19, remote work and global value chains. *The World Economy, 45*(2), 561-589.

Flori, E., Zhu, Y., Paterlini, S., Pattarin, F., and Villani, M. (2022). Spread of perturbations in supply chain networks: The effect of the bow-tie organization on the resilience of the global automotive system. In *Italian Workshop on Artificial Life and Evolutionary Computation*, 40-57. Cham: Springer Nature Switzerland.

Gaddi, M., and Garbellini, N. (2021). Automotive global value chains in Europe. *Institute for New Economic Thinking Working Paper Series, 160.*

Giglioli, S., Giovannetti, G., Marvasi, E., and Vivoli, A. (2021). The resilience of global value chains during the Covid-19 pandemic: The case of Italy. *DISEI Working Paper,* 7/2021, Università degli Studi di Firenze.

Giovannetti, G., Mancini, M., Marvasi, E., and Vannelli, G. (2020). Il ruolo delle catene globali del valore nella pandemia: effetti sulle imprese italiane. *Rivista di Politica Economica, 2*, 77-99.

Hufbauer, G. C., and Jung, E. (2021). Economic sanctions in the twenty-first century. *Research Handbook on Economic Sanctions*, 26-43.

Inoue, H., and Todo, Y. (2020). The propagation of economic impacts through supply chains: The case of a mega-city lockdown to prevent the spread of COVID-19. *PloS one, 15*(9), e0239251.

Jacobs, A. J. (2023). The Korean auto industry reaches maturity and internationalizes, 2005–2019. In The Korean Automotive Industry, Volume 2: Asian Crisis to Today, 1997–2020, 59-94. Cham: Springer International Publishing.

Klier, T. H., and Rubenstein, J. M. (2010). The changing geography of North American motor vehicle production. *Cambridge Journal of Regions, Economy and Society, 3*(3), 335-347.

Lema, R., Rabellotti, R., and Gehl Sampath, P. (2018). Innovation trajectories in developing countries: Co-evolution of global value chains and innovation systems. *The European Journal of Development Research, 30*(3), 345-363.

Lung, Y. (2004). The changing geography of the European automobile system. *International Journal of Automotive Technology and Management, 4*(2-3), 137-165.

Lüthje, B., and Tian, M. (2015). China's automotive industry: structural impediments to socio-economic rebalancing. *International Journal of Automotive Technology and Management, 15*(3), 244-267.

Lüthje, B. (2021). Going digital, going green: Changing production networks in the automotive industry in China. *International Journal of Automotive Technology and Management, 21*(1-2), 121-136.

Mair, A., Florida, R., and Kenney, M. (1988). The new geography of automobile production: Japanese transplants in North America. *Economic geography, 64*(4), 352-373.

Megyeri, E., Pelle, A., and Tabajdi, G. (2023). The realities of EU industrial policies analysed through automotive value chain dynamics. *Society and Economy, 45*(3), 250-269.

Moretti, A., and Zirpoli, F. (2020). Osservatorio sulla componentistica automotive italiana 2020. *Ricerche per l'innovazione nell'industria automotive, 5.*

Moro, A., and Virgillito, M. E. (2022). Towards factory 4.0? Convergence and divergence of lean models in Italian automotive plants. *International Journal of Automotive Technology and Management, 22*(2), 245-271.

Muniz, S. T. G., and Belzowski, B. M. (2017). Platforms to enhance electric vehicles' competitiveness. *International Journal of Automotive Technology and Management, 17*(2), 151-168.

Olejniczak, T., Miszczynski, M., and Itohisa, M. (2020). Between closure and Industry 4.0: strategies of Japanese automotive manufacturers in Central and Eastern Europe in reaction to labour market changes. *International Journal of Automotive Technology and Management, 20*(2), 196-214.

Pavlínek, P. (2018). Global production networks, foreign direct investment, and supplier linkages in the integrated peripheries of the automotive industry. *Economic Geography, 94*(2), 141-165.

Pavlínek, P. (2020). Restructuring and internationalization of the European automotive industry. *Journal of Economic Geography, 20*(2), 509-541.

Rarou, H. (2023). Global trends and spatiotemporal shifts in the automotive assembly footprint. *International Journal of Automotive Technology and Management, 23*(2-3), 121-143.

Schlie, E., and Yip, G. (2000). Regional follows global: Strategy mixes in the world automotive industry. *European Management Journal, 18*(4), 343-354.

Simonazzi, A., Carreto Sanginés, J., and Russo, M. (2022). The world to come: Key challenges for the automotive industry. *Economia e Lavoro, 57*(1), 7-23.

Smith, D. F., and Florida, R. (1994). Agglomeration and industrial location: An econometric analysis of Japan-affiliated manufacturing establishments in automotive-related industries. *Journal of Urban Economics, 36*, 23-41.

Sturgeon, T., and Florida, R. (2004). Globalization, deverticalization, and employment in the motor vehicle industry. In M. Kenney (Ed.), *Locating Global Advantage: Industry Dynamics in a Globalizing Economy*, 52-81. Stanford, Calif.: Stanford University Press.

Sturgeon, T., Van Biesebroeck, J., and Gereffi, G. (2008). Value chains, networks and clusters: reframing the global automotive industry. *Journal of Economic Geography, 8*(3), 297-321.

Sturgeon, T., and Van Biesebroeck, J. (2010). Effects of the crisis on the automotive industry in developing countries: a global value chain perspective. *World Bank Policy Research Working Paper, 5330.*

Thun, E. (2006). Changing lanes in China: Foreign direct investment, local governments, and auto sector development. Cambridge University Press.

Timmer, M. P., Dietzenbacher, E., Los, B., Stehrer, R., and De Vries, G. J. (2015). An illustrated user guide to the world input-output database: the case of global automotive production. *Review of International Economics, 23*(3), 575-605.

Wang, X., Zhao, W., and Ruet, J. (2022). Specialized vertical integration: the value-chain strategy of EV lithium-ion battery firms in China. *International Journal of Automotive Technology and Management, 22*(2), 178-201.

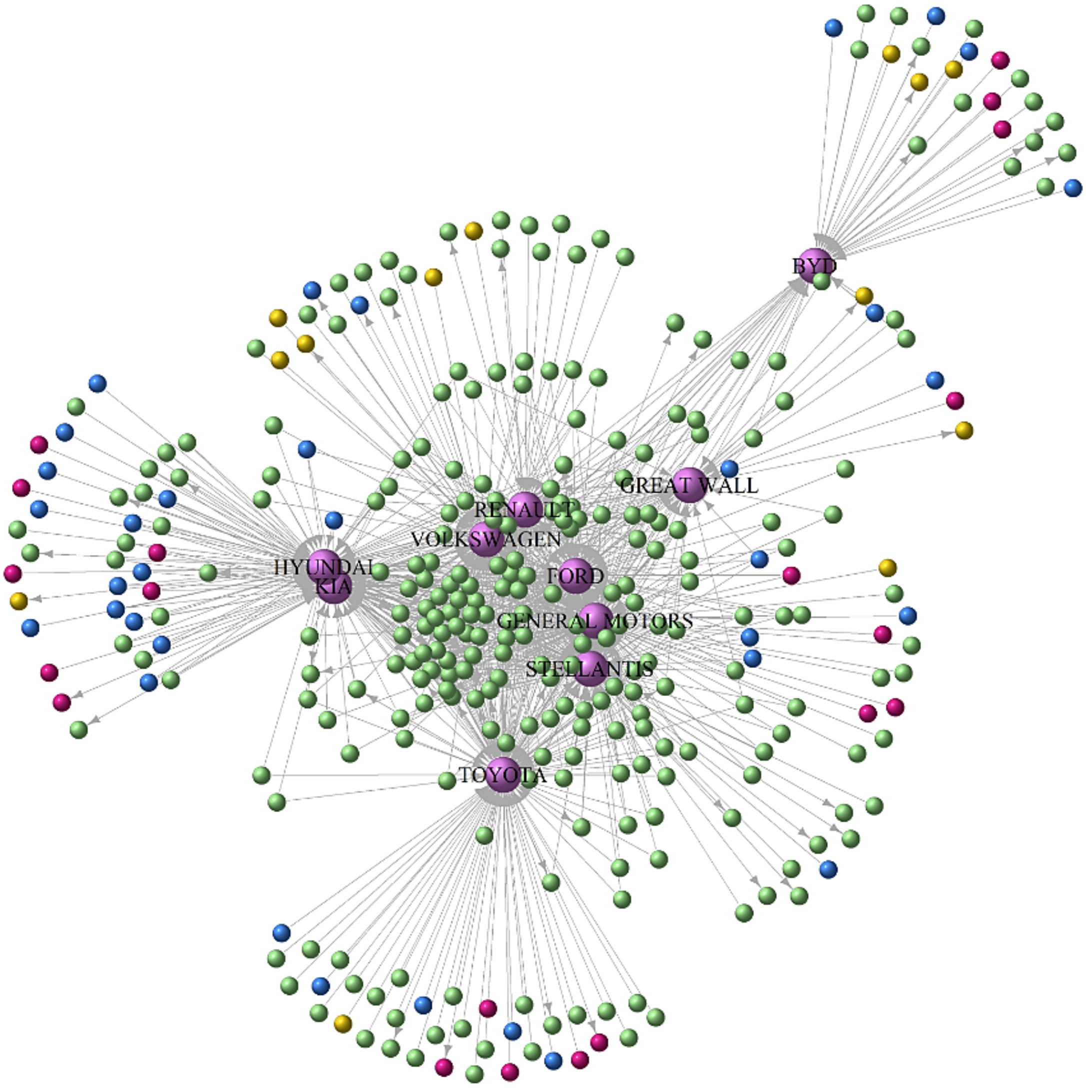
Womack, J. P., Jones, D. T., and Roos, D. (2017). The machine that changed the world. London&New York: Free Press (1st ed. 1990).

Appendix

Appendix A. Definition of geographic areas

Region	Countries
China	China
Japan	Japan
Other Asia	Hong Kong, Indonesia, Malesia, Philippines, Singapore, Sri Lanka, Taiwan, Thailand, Vietnam
North America	Canada, United States
South Korea	South Korea
Northern Europe	United Kingdom, Denmark, Finland, Ireland, Netherlands, Norway, Sweden
India	Bangladesh, India, Pakistan
Germany	Germany
France	France
Oceania	Australia, New Zealand
Central Europe	Austria, Belgium, Luxembourg, Switzerland
Eastern Europe and Russia	Croatia, Hungary, Poland, Romania, Russia, Serbia, Slovenia, Ukraine
Southern and Western Europe	Cyprus, Greece, Italy, Portugal, Spain
Latin America	Argentina, Brazil, Chile, Colombia, Mexico, Peru
Middle East	Israel, Jordan, Saudi Arabia, Turkey
Africa	Angola, Egypt, Mauritius, South Africa, Tunisia

Appendix B. Subnetwork extracted from the brand firms



Legend:

Only 1 arc

2 arcs

3, 4 or 5 arcs

6 or more arcs – no brand firms

6 or more arcs – brand firms

Appendix C. Arcs by region and industry

Region	In	Out	Tot
China	1,381	1,501	2,882
Japan	3,095	2,585	5,680
Other Asia	932	1,141	2,073
North America	2,201	2,232	4,433
South Korea	1,250	1,384	2,634
Northern Europe	420	509	929
India	335	376	711
Germany	412	601	1,013
France	328	354	682
Oceania	80	55	135
Central Europe	352	142	494
Eastern Europe and Russia	82	85	167
Southern and Western Europe	164	97	261
Latin America	77	71	148
Middle East	63	34	97
Africa	10	15	25
Total	11,182	11,182	22,364

Industry	In	Out	Tot
Electronic components	1,730	1,359	3,089
Auto parts and equipment	3,406	1,550	4,956
Steel	1,330	1,266	2,596
Application software	1,077	396	1,473
Industrial machinery	304	134	438
Semiconductors	300	86	386
Automobile manufacturers	350	2,650	3,000
Semiconductor equipment	134	18	152

Distributors	103	275	378
Technology hardware, storage and peripherals	95	305	400
Construction machinery and heavy trucks	101	357	458
Construction and engineering	73	97	170
Electronic components and equipment	134	84	218
Commodity chemicals	151	34	185
Trucking	60	166	226
Electronic equipment and instruments	105	49	154
Technology distributors	97	206	303
Trading companies and distributors	78	110	188
IT consulting and other services	72	75	147
Communications equipment	38	65	103
Other	1,444	1,900	6,341
Total	11,182	11,182	22,364

Appendix D. Regional and industrial overlapping between brand subnetworks

Region	*General Motors versus Toyota*	*General Motors versus Volkswagen*	*General Motors versus Great Wall*	*Toyota versus Volkswagen*	*Toyota versus Great Wall*	*Volkswagen versus Great Wall*
Central Europe	3	4	1	3	0	1
China	2	2	1	2	1	1
France	5	6	2	6	2	2
Germany	5	8	1	5	1	1
India	3	3	0	3	0	0
Japan	42	30	7	30	8	6
North America	30	31	8	30	6	7
Northern Europe	5	6	5	5	4	5
Other Asia	0	0	0	1	0	0
Eastern Europe and Russia	0	1	0	0	0	0
Latin America	1	1	0	1	0	0
Southern and Western Europe	3	4	1	3	1	1
South Korea	0	2	1	0	0	1
Total	99	98	27	89	23	25

Industry	*General Motors versus Toyota*	*General Motors versus Volkswagen*	*General Motors versus Great Wall*	*Toyota versus Volkswagen*	*Toyota versus Great Wall*	*Volkswagen versus Great Wall*
Application software	2	1	0	2	0	0
Auto parts and equipment	72	75	25	65	22	24
Automotive retail	7	7	1	7	0	0
Distributors	1	1	0	1	1	1
Electronic components	4	4	0	3	0	0
Electronic equipment and instruments	1	0	0	0	0	0
Electronic manufacturing services	0	0	1	0	0	0
Steel	10	8	0	8	0	0
Trucking	2	2	0	3	0	0
Total	99	98	27	89	23	25

Appendix E. An overview of the automotive network in Modena area

This appendix provides a brief analysis of the primary nodes in the automotive industry's network, based on data collected by the local branch of the National Confederation of Craftsmen and Small and Medium Enterprises (CNA), which is affiliated with CNEL. The data focuses on small and medium-sized enterprises (SMEs) in the craft sector. It was collected by examining invoices issued by 129 commissioning companies located in the province of Modena, all of which possess an ATECO code of 29.10.00. The list of commissioning companies was obtained from mandatory communications (COB). The companies in the network primarily act as either customers or suppliers, as shown in Table 1. After analysing the invoice data from 2018 to 2021, it was found that 747 nodes were involved. Of these, 129 customers represented 17.3% of the total, while 618 suppliers represented the remaining 82.7%. The network had a total of 1452 business connections during this period.

Type of node	Absolute frequency	Relative frequency (%)
Suppliers	618	82,7
Costumers	129	17,3
Total	747	100,0

Table 1. Frequency of the automotive network companies by node typology in Modena.

Table 2 presents statistical information on the number of connections established by each company. This analysis helps determine the average number of suppliers linked to each contracting company, providing insight into the length of the supply chain.

Minimum	1st Quartile	Median	Mean	3rd Quartile	Maximum
1.00	2.00	3.00	6.44	8.00	82.00

Table 2. Statistics on the arc distribution of the automotive network in Modena.

On average, each customer is connected to 6.44 suppliers in the supply chain. However, one company has connections with as many as 82 suppliers in the supply chain. Table 3 presents the top ten companies in Modena province with the highest number of connections within their supplier network.

Firms	Arcs
Cierre S.r.l.	82
Carrozzeria M.M di Corradi V. and C. snc	40

FCA Italy S.p.A.	36
Orap di Volpi Giuliano and F.lli snc	29
Stella Impianti S.r.l.	26
Car Aleotti snc	25
Ferrari S.p.A.	24
Reflexallen S.p.A.	21
Tecnoelettra Impianti S.r.l.	18
Modena Motori Class E Sport S.r.l.	15

Table 3. Arcs of the automotive network by single firm in Modena (top 10).

Cierre S.r.L. stands out with 82 connections with suppliers in their network, resulting in a more complex arc structure than other companies. FCA Italy S.p.A has a structure comprising 36 connections while Ferrari S.p.A has 24 more connections than the average of the analyzed sample. The top ten companies based on arc size have an average of 31.6 connections with supplier companies, which is considerably higher than the majority of the remaining sample that only has a few connections. Table 4 showcases where companies in the Modena province operate in the local automotive supply chain.

District	Firms	Relative frequency (%)
Vignola	189	22,8
Nord Area	172	20,7
Modena	125	15,0
Sassuolo	124	14,9
Carpi	122	14,7
Apennine Area	43	5,2
Others	56	6,7
Total	831	100,0

Table 4. Number of firms of the automotive network by district.

Table 5 presents a comprehensive breakdown of the various sectors that constitute the supply chain in Modena province.

Industrial activities	Firms	Relative frequency (%)
Trucking	120	14,5
Maintenance of mechanical parts	76	9,1
Installation and maintenance of electrical components	45	5,4
Mechanical works	40	4,8
Maintenance of vehicle	39	4,7
Maintenance of car body	27	3,2
Installation and maintenance of air conditioning systems	25	3
Car tinting	19	2,3
Others	440	53,0
Total	831	100,0

Table 5. Number of firms of the automotive network by sector in Modena (top 9).

Table 6 provides an overview of supplier distribution within the area and examines the ten most notable companies in the region, considering the size of their respective arcs.

Firms	Total	Vignola	Nord Area	Modena	Carpi	Sassuolo	Apennine Area	Others
Cierre S.r.l.	82	18	34	6	1	11	2	10
Carrozzeria M.M di Corradi V. and C. snc	40	0	13	3	17	5	0	2
FCA Italy S.p.A.	36	11	14	1	4	1	4	1
Orap di Volpi Giuliano and F.lli snc	29	3	10	3	1	0	10	2
Stella Impianti s.r.l.	26	2	1	2	1	16	2	2
Car Aleotti snc	25	13	4	3	2	2	0	1

Ferrari S.p.A.	24	5	0	1	1	15	1	1
Reflexallen S.p.A.	21	16	0	1	4	0	0	0
Tecnoelettra Impianti S.r.l.	18	13	0	0	0	2	2	1
Modena Motori Class E Sport S.r.l.	15	0	4	10	1	0	0	0

Table 6. Number of firms of the automotive network by district and company in Modena.

In Table 7, we analyze the most important brands according to the size of the supply chain, highlighting the main sectors of activity of the suppliers.

Firms	Total	Others	Maintenance of car body	Installation of air conditioning	Installation of electrical parts	Maintenance of vehicle	Mechanical works	Maintenance of mechanical parts	Car tinting	Trucking
Cierre S.r.l.	82	16	0	0	2	0	0	0	0	64
Carrozzeria M.M di Corradi V. and C. snc	40	22	3	2	2	1	0	3	2	5
FCA Italy S.p.A.	36	3	2	0	1	1	0	29	0	0
Orap di Volpi Giuliano and F.lli snc	29	8	1	1	1	3	0	13	0	2
Stella Impianti s.r.l.	26	8	0	0	2	6	0	0	0	10
Car Aleotti snc	25	12	1	0	2	3	0	0	0	7
Ferrari S.p.A.	24	15	0	1	2	2	2	0	2	0
Reflexallen S.p.A.	21	12	0	2	1	1	1	2	2	0
Tecnoelettra Impianti S.r.l.	18	11	1	2	1	0	3	0	0	0
Modena Motori Class E Sport S.r.l.	15	8	0	2	2	0	1	2	0	0

Table 7. Number of firms of the automotive network by sector and company in Modena.

Table 8 analyses the local supply chains of several major global OEMs operating within the province, including Ferrari, FCA, Lamborghini, Maserati, Pagani, and Dallara.

Firms	Total	Vignola	Nord Area	Modena	Carpi	Sassuolo	Apennine Area	Others
FCA	36	11	14	1	4	1	4	1
Ferrari	24	5	0	1	1	15	1	1
Pagani	18	2	0	6	2	7	1	0
Lamborghini	14	2	1	4	2	2	0	3
Maserati	11	1	0	2	1	5	1	1
Dallara	1	0	0	0	0	0	1	0

Table 8. Number of firms of the automotive network by sector and main final producer in Modena province.

Table 9 analyses the overlap between the supply chains of the six global brands to identify similarities and differences in production strategies.

Firms	Vignola	Nord Area	Modena	Carpi	Sassuolo	Apennine Area
Ferrari-Lamborghini	2	0	0	1	0	1
Maserati-Pagani	0	0	2	0	0	0
Ferrari-Maserati	0	0	1	0	0	0
Ferrari-Dallara	0	0	0	0	1	0
Maserati-Lamborghini	0	1	0	0	0	0

Table 9. Number of overlaps by sector and main final producer in Modena province.

Chapter 2

Worldwide partnership: fueling global brands

Giuseppe Caruso and Giovanni Solinas

1. Introduction[8]

Even leaving aside the many well-known shocks that have occurred in recent years (from the financial and economic crisis to increasingly rapid technical-organisational progress; from the pandemic to the ecological transition, etc.), the automotive industry suffers from ancient structural ills: overcapacity, an increasingly shorter product life with high research and development costs, the need to contract the time to market, etc. All with major effects on profits.

In recent years, carmakers (OEMs) have reacted to these difficulties with waves of mergers and by increasingly operating on a global scale (Iapadre and Tajoli (2014), Lee et al. (2015) and Gereffi et al. (2016). The final manufacturers are now far fewer in number than in other manufacturing sectors precisely because of the high barriers to entry and the high investment required, they have progressively contracted their production base and the vertical integration of individual plants by concentrating on scale-intensive high-tech activities, focusing on flexible production platforms capable of producing different car models, and using increasingly driven organisational forms of lean production (Lall et al., 2004; Amighini et al., 2014). The adjustment costs of these transformations were at least partially passed on to the suppliers of parts and components.

Also, in connection with these choices of carmakers, a large market space for the development of global value chains (GVCs) has been created. Over time, a highly globalised network involved in the different stages of the assembly and marketing of vehicles has emerged (Ruigrok and van Tulder, 1991; Gereffi and Korzeniewicz, 1994; Lee and Cason, 1994).

According to the OECD (2007), new production strategies that rely heavily on outsourcing have resulted in 70-75% of the value added in new vehicles going to suppliers. Key suppliers invest according to the needs of OEMs and in regions suitable for global expansion. This has

[8] The authors wish to thank Elisa Flori and Francesco Pattarin for allowing us to use the Bloomberg database (cf. section 2).

led to a natural proliferation of global suppliers who invest in regions suitable for global expansion and in line with the needs of OEMs although carmakers maintain a crucial role in monitoring and managing their first and second-tier supply networks, distributed globally and increasingly located in emerging markets, e.g. in Asia and Eastern Europe (Dicken, 2003; Rhys, 2004; Noble, 2006; Lefilleur, 2008).

Carmakers have moved their factories closer to the end users to improve product customization and align production steps with specific consumer demands. Consequently, suppliers are located near primary production plants to reduce transport costs and facilitate production settings (Sturgeon and Florida, 2004; Sturgeon et al., 2008).

In the automotive industry, there have been opposing drives toward globalisation and regionalisation of value chains (Baldwin and Lopez-Gonzalez, 2015; Timmer et al., 2015; Gorgoni et al., 2018). Sturgeon et al. (2008) argue that the automotive industry is not fully global, consisting of highly interconnected and specialised clusters, nor is it fully concentrated in specific regions or areas (Frigant and Zumpe, 2017; Kano et al., 2020). Since the 1990s, there has been an increase in international agreements between geographically distant regions, resulting in the inclusion of emerging and transition economies such as China, India and Brazil in the automotive supply chain.

The automotive industry today faces a situation of serious uncertainty. In addition to the long-standing structural weaknesses mentioned above, new difficulties have been added to make the behaviours and choices of manufacturers in the entire value chain even more difficult: stagnating demand in most industrially developed countries, increasingly stringent regulations for the reduction of GHC emissions and the emergence of new fuels and new engines, the progressive change in the business model – from a model built on individual car ownership to one aimed at providing mobility services.

These transformations involve both final manufacturers and suppliers of parts and components and will have a major impact on the overall structure of value chains. Even more so as the speed at which these processes will take place remains largely unknown.

Building on this highly evolving scenario and developing on our earlier study (Flori et. al, 2024), this essay aims to provide some insights into a specific aspect: the size of OMEs' suppliers and the consequences of their size for the industry at large. To this end, attention is focused on the supply relationships of ten of the best-known brands in the world industry: General Motors, Ford, Stellantis, Volkswagen, Renault, Toyota, Hyundai, Kia, BYD, and Great Wall.

Section 2 describes the source of the data and the dataset building; section 3 presents the main results; section 4 concludes.

2. Data sources and dataset building

Our study is based on data from Bloomberg sources on the customer-supplier relationship network. Company data are classified according to Morgan Stanley Capital International and Standard and Poor's GICS taxonomies. The information provided by Bloomberg includes company size, average annual revenue in USD millions for fiscal years 2018-2020, legal address of the company, and industrial activities. Bloomberg archive includes only stock exchange-listed companies.

The data collection process started with the identification and acquisition of information from Bloomberg on the world's leading manufacturers of cars, motorcycles, trucks, and heavy vehicles. A total of 165 companies were identified as focal companies. For each focal company, the database contains the set of variables described above and some information on main suppliers and clients. In turn, the same information is available for each of the major suppliers and clients. In this sense, the dataset contains information on first and second-tier suppliers and provides a reasonable picture of the automotive GVC as a whole (Flori et al., 2022 and 2024). The full dataset consists of 3,323 companies linked by 11,182 key business relationships.

The database used, whose characteristics have been briefly described, also has limitations that must be made explicit. It only includes 'important' relationships (listed firms) and does not provide an accurate measure of exchanges between producers and suppliers over a defined time interval, either in terms of amounts or in terms of the frequency of exchanges. In terms of network analysis, one could say that it allows us to construct nodes and arcs, but it does not give us the thickness of the latter. It is, however, a non-negligible tool for reconstructing the relationships between final firms and supply chains.

The potential of the mentioned dataset for the study of automotive GVCs is presented in other essays. For the topic discussed in these pages, it is sufficient to consider only the supply relationships between the ten car manufacturers mentioned above, and their main suppliers and within the network that includes the 10 final carmakers (343 companies). Excluding intra-group trade between manufacturers and some distributors, almost all suppliers are Tier-I suppliers.

3. Key global suppliers

The analysis of the supply chain shows that the network of the ten OEMs includes several critical suppliers. The supply network comprises a total of 343 key suppliers. These key suppliers are involved in a range of industrial activities, including the production of steel&aluminium, electrical equipment, industrial machinery, tires and rubber, as well as service and distribution.

Before attempting to identify who the key suppliers are to the ten end producers, it is useful to look at the overall exchanges involving the entire network of which the ten end producers are part. There are two results to highlight.

The first is the emergence of a significant core of large suppliers offering raw materials, semi-finished products, industrial machinery, parts and components to intermediate and final manufacturers. This is the case with steel and aluminium smelters. The Korean Posco supplies steel to 105 companies included in the network; the Nippon Steel Corporation to 86; Arcelor Mittal to 73; Thyssenkrupp to 68 and so on. Similar considerations apply to suppliers of semiconductors, of which there are only four in the period under consideration, or to tire manufacturers: only three supply tires to the automakers in the network: the French Michelin (CGDE), the Chinese Tianjin Pengling Group and the American Goodyear.

The presence of a significant core of intermediate manufacturers supplying a large number of companies also affects other sectors. To give just a few examples: Microsoft for consumer electronics and software systems enter everywhere as does Dell Technologies for computers and peripherals. The Japanese Panasonic has supply contracts with 69 companies; the American Arrow Electronics with 55; the Korean LG with its various divisions supplies more than 100 companies in the ten-brand network. A very substantial core of large suppliers can also be seen among the manufacturers of parts and components, including electronic components: the Japanese Denso Corp. alone supplies 107 companies in the network; the American Magna International Inc. 87, etc. In this sense, and even considering that we are not able to have detailed information on small suppliers, considering activated supply contracts (and realised turnovers) the component market also appears relatively concentrated.

The second feature to be emphasised concerns the territorial distribution of supplies. Even considering the territorial affiliation of the companies being examined, there is a strong concentration of supplies in Asian countries. Among manufacturers of parts and components, Asian suppliers account for 67% (with Japan alone accounting for 37% of the total); Europeans for 15%. In the electronic components compartment, Europe counts even less (10.3%) and North America shares the market. The competitive game is here between North America (34.4%) and Asian countries (53.4%), with China alone weighing over 20%.

Table 1 provides an overview of these results showing the top 15 suppliers, ranked by average annual revenue, involved in at least one major OEM's production chain between 2018-2020.

Key Suppliers	Industry	Region	Sales (USD mln)
Microsoft Corp	Systems Software	North America	126406
Dell Technologies	Technology Hardware, Storage and Peripherals	North America	87272
Hitachi Ltd	Electronic Equipment and Instruments Industry	Japan	83575
Intl Business Machines Corp	IT Consulting and Other Services	North America	76786
Panasonic Corp	Consumer Electronics	Japan	71045
Basf Se	Diversified Chemicals	Germany	68354
ArcelorMittal	Steel	Center Europe	66639
Toyota Tsusho Corp	Trading Companies and Distribution	Japan	60388
Posco	Steel	South Korea	54466
Nippon Steel Corp	Steel	Japan	53920
Continental Ag	Auto Parts and Equipment	Germany	48436
DENSO CORP	Auto Parts and Equipment	Japan	47295
Thyssenkrupp Ag	Steel	Germany	40070
Magna International Inc	Auto Parts and Equipment	North America	37635
Aisin Corp	Auto Parts and Equipment	Japan	35522

Table 1. The fifteen largest Key Suppliers by region and by sales

In the last two figures, the perspective of analysis changes. Figure 1 shows the links between key suppliers and major OEMs. The table identifies the top 15 suppliers according to Bloomberg that had business relationships with at least eight of the ten OEMs. These suppliers have a significant global presence and participate in the supply chains of manufacturers located in distant areas. Faurecia, Valeo SA, Adient PLC, Magna International Inc, Autoliv Inc and Aptiv PLC are the six suppliers that participated in the production chains of all the top ten OEMs during the period analysed. These companies are located in North America, France, and

Northern Europe. Thirteen of the fifteen suppliers produce car components, indicating their growing involvement in the manufacturing operations of multiple OEMs around the world.[9]

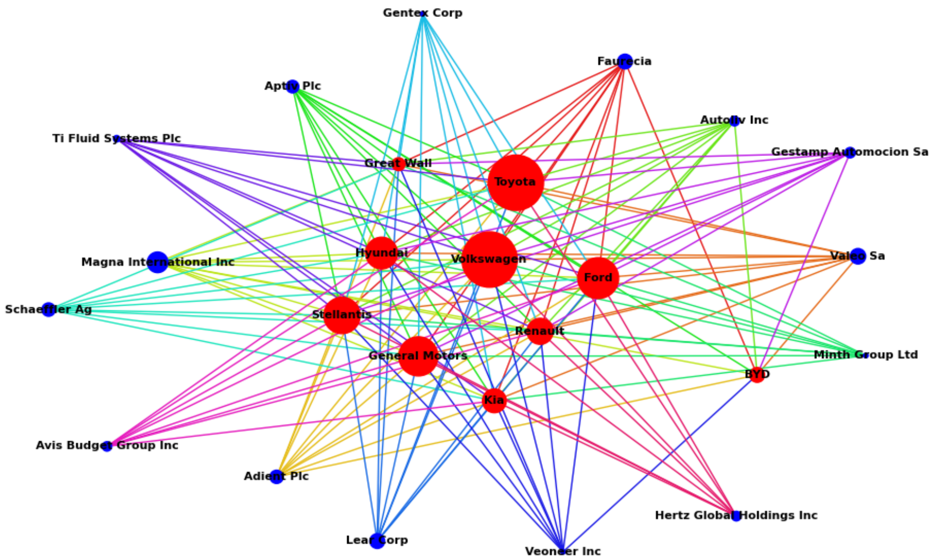


Figure 1. Linkages between Key Suppliers and OEMs

Source: Elaboration on Bloomberg data

The results are further refined by controlling for the economic size of key suppliers. Figure 2 presents only those suppliers that have an average annual turnover of at least 10 billion USD over the period from 2018 to 2020.

[9] It is worth noting that all ten major OEMs are supplied by the two French suppliers, Faurecia and Valeo Sa. In contrast, North American suppliers provide for all brands except Chinese companies. It is important to note that BYD only deals with two of the six American companies. Great Wall only deals with four of the six. Notable is the growth of Chinese companies such as Minth Group Ltd, which has a turnover of almost 2 billion and is a supplier to nine of the ten brands, except BYD. Gestamp Automocion Sa, a company based in Southwestern Europe, is a supplier of automotive components to all OEMs except Kia

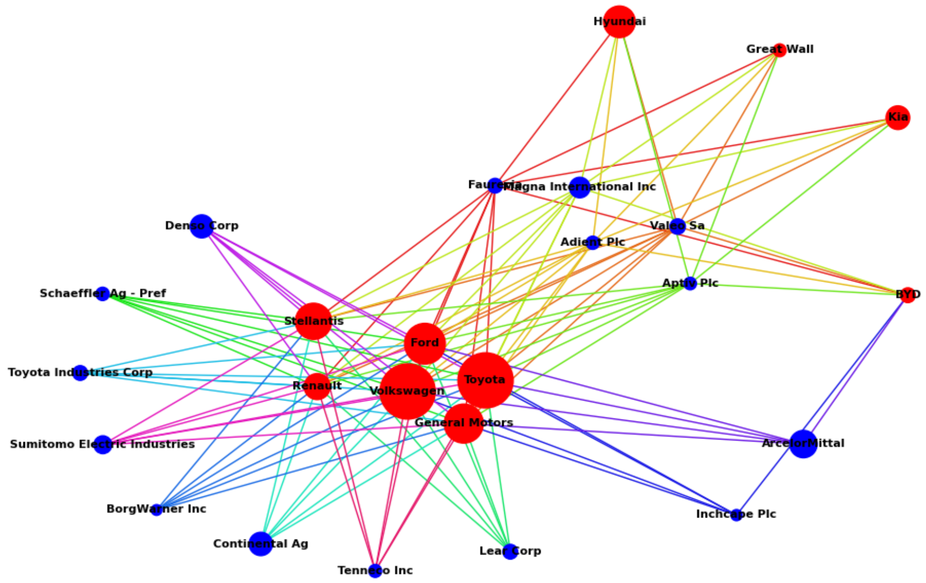


Figure 2. Linkages between Key Suppliers with sales over 10 billion and OEMs

Source: Elaboration on Bloomberg data

The figure highlights the links between key suppliers and OEMs. As the figure shows, most of them provide components and parts for the cars. And most of them have global sales comparable to that of major producers.[10]

It is difficult to imagine that suppliers of this size with relationships with many of the OMEs do not have a major influence on the organisation of GVC, on the rules of competition in the global industry, and, ultimately, do not play a major role in the distribution of profits.

4. Final remarks

We would like to conclude with very few comments.

The first concerns the role of the European parts and components suppliers. Although we have chosen to build the network by including three major brands such as Stellantis, Renault and Volkswagen among the final producers, the role of European parts and components suppliers (Tier-I) is much smaller than that of suppliers elsewhere: in the ranking built on the

[10] Companies such as the French Faurecia and Valeo SA (with sales of respectively 19 billion and 21 billion USD) continue to play an important role in the production network. Japanese supplier Denso Corp (with sales of 47 billion USD), are suppliers for seven of the ten OEMs, excluding BYD, Great Wall, and Renault. Continental AG and Denso Corporation have sales comparable to Kia's and both exceed those of the two Chinese companies. On average, except for the Chinese companies BYD and Great Wall, all brands are associated with the three biggest Japanese key providers: Toyota Industries Corp, Denso Corp and Sumitomo Electric Industries.

sales of the 243 companies that Bloomberg gives us, the German companies Continental and Schaeffler or Hella GMBH and CO KGAA, or the oft-mentioned French Faurecia and Valeo, certainly play important roles; but other well-known producers slide down. There are very few Italians.[11]. In an overall picture in which 'volumes' have weight, even important and well-known suppliers of parts and components play a marginal role compared to the large Asian market.

The second issue concerns the relationship, again in terms of size, between carmakers and component manufacturers. If the picture sketched in the previous pages is correct, the emergence of an important group of key players who often manage to be the partner of a large part of the final brands leads to the conclusion that this cannot be considered a 'manufacturer' market' (Dalla et al. 2019; Raj-Reichert, 2019). Key tier-1 suppliers bring scale and efficiency to the industry, their market power can lead to various challenges in the automotive supply chain: from manufacturers' over-dependence on the supply of strategic components to the rising cost of components; from a lack of flexibility in the adoption of new technologies, to a reduced ability to react quickly to shifts in consumer preferences; from the emergence of barriers to entry concerning specific technologies, to reduced responsiveness and resilience to unforeseen and disruptive events.

In day-to-day operations, a major problem can arise in terms of quality. "Big suppliers may face challenges in maintaining consistent quality and compliance across their vast operations. Any lapses in quality or compliance can have significant repercussions throughout the supply chain, impacting the reputation and performance of carmakers". The relevant point is that these problems may become more acute in a scenario of great uncertainty and the sequence of exogenous shocks that have characterised the last decades. Car manufacturers, in particular, may be even more exposed to the market power of key suppliers under conditions of epochal transformation related to electrification, digitisation and autonomous driving (Bernhart and Alexander, 2020; Deloitte, 2020; 2023a and 2023b).

This is a reasonable explanation as to why in recent years we have seen forms of collaboration and partnerships between carmakers (i.e BMW and Daimler; Ford and

[11] The top Italian parts and components manufacturer, for example, is Brembo (manufacturer of braking systems) which occupies 117th position; followed by the Sogefi group (manufacturer of filtration systems and suspension components) which occupies 159th position. A manufacturer such as Marelli does not enter among the top key suppliers. More generally, the role of Italian manufacturers compared to French manufacturers is perhaps one of the keys to understanding some of Stellantis' recent choices.

Volkswagen; Honda and General Motors) that would have been completely unthinkable a few years ago.

References

Amighini, A., and Gorgoni, S. (2014). The international reorganisation of auto production. The *World Economy, 37*(7), 923-952.

Baldwin, R., and Lopez-Gonzalez, J. (2015). Supply-chain trade: A portrait of global patterns and several testable hypotheses. *The World Economy, 38*(11), 1682-1721.

Bernhart, W. and Alexander, M. (2020). Computer on wheels: Disruption in automotive electronic and semiconductor. Roland Berger.

Dallas, M. P., Ponte, S., and Sturgeon, T. J. (2019). Power in global value chains. *Review of International Political Economy, 26*(4), 666-694.

Deloitte. (2020). Think tank. Automotive White Paper.

Deloitte. (2023). Automotive supplier study.

Deloitte. (2023). The future of automotive value chain. 2025 and beyond.

Dicken, P. (2003). Global shift: Reshaping the global economic map in the 21st century. Sage.

Flori, E., Zhu, Y., Paterlini, S., Pattarin, F., and Villani, M. (2022). Spread of perturbations in supply chain networks: The effect of the bow-tie organization on the resilience of the global automotive system. In *Italian Workshop on Artificial Life and Evolutionary Computation,* 40-57. Cham: Springer Nature Switzerland.

Flori, E., Caruso, G., Pattarin, P. and Solinas, G. (2024). The global structure of the automotive industry: a network-based view. *International Journal of Automotive Technology and Management.* (in print, accepted, Jan. 24th, 2024)

Frigant, V., and Zumpe, M. (2017). Regionalisation or globalisation of automotive production networks? Lessons from import patterns of four European countries. *Growth and Change, 48*(4), 661-681.

Gereffi, G., and Korzeniewicz, M. (Eds.). (1993). Commodity chains and global capitalism. Bloomsbury Publishing USA.

Gereffi, G., and Sturgeon, T. (2004). Globalization, employment, and economic development: a briefing paper. Sloan *Workshop Series in Industry Studies 1*, 2. Rockport, Massachusetts.

Gereffi, G., and Fernandez-Stark, K. (2016). Global value chain analysis: a primer.

Gorgoni, S., Amighini, A., and Smith, M. (2018). Automotive international trade networks: A comparative analysis over the last two decades. *Network Science, 6*(4), 571-606.

Iapadre, P. L., and Tajoli, L. (2014). Emerging countries and trade regionalization. A network analysis. *Journal of Policy Modeling, 36*, S89-S110.

Kano, L., Tsang, E. W., and Yeung, H. W. C. (2020). Global value chains: A review of the multi-disciplinary literature. *Journal of International Business Studies*, *51*, 577-622.

Lall, S., Albaladejo, M., and Zhang, J. (2004). Mapping fragmentation: electronics and automobiles in East Asia and Latin America. *Oxford Development Studies, 32*(3), 407-432.

Lee, N., and Cason, J. (1994). Automobile commodity chains in the NICs: a comparison of South Korea, Mexico, and Brazil. *Commodity Chains and Global Capitalism, 149*, 223.

Lee, J., and Gereffi, G. (2015). Global value chains, rising power firms and economic and social upgrading. *Critical Perspectives on International Business, 11*(3/4), 319-339.

Lefilleur, J. (2008). Geographic reorganization of the European automobile sector: What role for the Central and East European countries in an enlarged European Union? An empirical approach. *Eastern European Economics, 46*(5), 69-91

MacDuffie, J. P. (2013). Modularity-as-property, modularization-as-process, and ‘modularity'-as-frame: Lessons from product architecture initiatives in the global automotive industry. *Global strategy journal*, *3*(1), 8-40.

Noble, W. S. (2006). What is a support vector machine?. *Nature Biotechnology, 24*(12), 1565-1567.

Pavlínek, P. (2012). The internationalization of corporate R&D and the automotive industry R&D of East-Central Europe. *Economic Geography, 88*(3), 279-310.

Raj-Reichert, G. (2019). 22. The role of transnational first-tier suppliers in GVC governance. *Handbook on global value chains, 354.*

Rhys, D. G. (2004). The motor industry in an enlarged EU. *World Economy, 27*(6), 877-900.

Ruigrok, W., and Van Tulder, R. (2013). The logic of international restructuring: The management of dependencies in rival industrial complexes. Routledge.

Simonazzi, A., Carreto Sanginés, J., and Russo, M. (2022). The world to come: key challenges for the automotive industry. *Economia e lavoro, 57*(1), 7-23.

Sturgeon, T., Van Biesebroeck, J., and Gereffi, G. (2008). Value chains, networks and clusters: reframing the global automotive industry. *Journal of Economic Geography, 8*(3), 297-321.

Appendix

Appendix A. Linkages between Key Suppliers and OEMs

Key Suppliers	Industry	Region	Sales (USD mln)	General Motors	Ford	Kia	Renault	Volkswagen	Stellantis	Hyundai	Toyota	Great Wall	BYD
Faurecia	Auto Parts & Equipment	France	19107	1	1	1	1	1	1	1	1	1	1
Valeo Sa	Auto Parts & Equipment	France	21053	1	1	1	1	1	1	1	1	1	1
Adient Plc	Auto Parts & Equipment	North America	15545	1	1	1	1	1	1	1	1	1	1
Magna International Inc	Auto Parts & Equipment	North America	37635	1	1	1	1	1	1	1	1	1	1
Autoliv Inc	Auto Parts & Equipment	Northern Europe	8224	1	1	1	1	1	1	1	1	1	1
Aptiv Plc	Auto Parts & Equipment	Northern Europe	13953	1	1	1	1	1	1	1	1	1	1
Minth Group Ltd	Auto Parts & Equipment	China	1873	1	1	1	1	1	1	1	1	1	0
Schaeffler Ag	Auto Parts & Equipment	Germany	15785	1	1	1	1	1	1	1	1	1	0
Gentex Corp	Auto Parts & Equipment	North America	1794	1	1	1	1	1	1	1	1	1	0
Lear Corp	Auto Parts & Equipment	North America	19335	1	1	1	1	1	1	1	1	1	0
Veoneer Inc	Auto Parts & Equipment	Northern Europe	1834	1	1	1	1	1	1	1	0	1	1
Ti Fluid Systems Plc	Auto Parts & Equipment	Northern Europe	3711	1	1	1	1	1	1	1	1	1	0
Gestamp Automocion Sa	Auto Parts & Equipment	South and West Europe	9586	1	1	0	1	1	1	1	1	1	1

Avis Budget Group Inc	Trucking	North America	7899	1	1	1	1	1	1	1	1	0	0
Hertz Global Holdings Inc	Trucking	North America	8180	1	1	1	1	1	1	1	1	0	0

Appendix B. Linkages between Key Suppliers with sales over 10 billion and OEMs

Key Suppliers	Industry	Region	Sales (USD mln)	General Motors	Ford	Kia	Renault	Volkswagen	Stellantis	Hyundai	Toyota	Great Wall	BYD
Faurecia	Auto Parts & Equipment	France	19107	1	1	1	1	1	1	1	1	1	1
Valeo Sa	Auto Parts & Equipment	France	21053	1	1	1	1	1	1	1	1	1	1
Adient Plc	Auto Parts & Equipment	North America	15545	1	1	1	1	1	1	1	1	1	1
Magna International Inc	Auto Parts & Equipment	North America	37635	1	1	1	1	1	1	1	1	1	1
Aptiv Plc	Auto Parts & Equipment	Northern Europe	13953	1	1	1	1	1	1	1	1	1	1
Schaeffler Ag - Pref	Auto Parts & Equipment	Germany	15785	1	1	1	1	1	1	1	1	1	0
Lear Corp	Auto Parts & Equipment	North America	19335	1	1	1	1	1	1	1	1	1	0
Continental Ag	Auto Parts & Equipment	Germany	48436	1	1	1	1	1	1	1	1	0	0
Toyota Industries Corp	Auto Parts & Equipment	Japan	19347	1	1	1	1	1	1	1	1	0	0
BorgWarner Inc	Auto Parts & Equipment	North America	10288	1	1	1	1	1	1	1	0	1	0
Inchcape Plc	Distributors	Northern Europe	11047	1	1	1	0	1	0	1	1	1	1
ArcelorMittal	Steel	Center Europe	66639	1	1	0	1	1	1	0	1	0	1

Denso Corp	Auto Parts & Equipment	Japan	47295	1	1	1	0	1	1	1	1	0	0
Sumitomo Electric Industries	Auto Parts & Equipment	Japan	28356	1	0	1	1	1	1	1	1	0	0
Tenneco Inc	Auto Parts & Equipment	North America	14864	1	1	0	1	1	1	0	1	1	0

Chapter 3

Labour demand and skill evolution in the automotive industry: A case study of Emilian Motorvalley

1. Introduction

The automotive industry has been a key driver of manufacturing in Emilia-Romagna for decades, contributing significantly to the region's economic growth. The Emilia-Romagna automotive industry is a highly interesting observatory for studying the labour market.

There are three reasons. The first reason is the simultaneous presence of internationally important companies and suppliers of parts and components to European industry. The region is home to several large premium manufacturers, including Ferrari, Lamborghini and Maserati, as well as numerous small and medium-sized firms that supply the industry in Europe (Russo and Pentucci, 2019). Local suppliers have played a central role in the production structure of the continent's major final manufacturers since the last century. In 2016, the region's automotive industry exported goods worth €5.9 billion, representing 15.9% of Italy's total exports. This provides a clear indication of the competitiveness of Emilia-Romagna's automotive industry on a global scale (Russo, 2018). Emilia-Romagna is also the third Italian province in terms of active automotive firms, with 228 firms, behind Piemonte (752) and Lombardia (598), and the region currently employs 16,495 people in the industry, representing 6.9% of the automotive workforce in Italy (Moretti and Zirpoli, 2019).

The second reason is that the regional automotive industry is a good place to study the impact of technological progress and digitalisation on the demand for labour. Technological development has had a significant impact on the evolution of the production process in the automotive industry. This has also affected the local industry. The change in the production process in the automotive industry is a complex issue and requires an in-depth analysis of different aspects.

Since the First Industrial Revolution, companies have aimed to integrate new technologies to increase productivity, reduce costs and generate revenue (Pianta, 2018). Integrating new technologies is associated with acquiring new skills through employment (Grillitsch et al., 2018). As early as the last century, the US Bureau of Labor Statistics (BLS) has emphasized the importance of monitoring the changing demand for skills related to technological advances and production processes that affect the economy (Wilson, 2013).

The evidence suggests that the early 20th century marked a turning point in the complementary relationship between skill and technology (Attewell, 1992; Goldin and Katz, 1998). There has been an increase in academic interest in the role of human capital in skills development (Fulmer and Ployhart, 2014). This necessitates that firms cultivate human capital (Barney, 1991; Becker and Gerhart, 1996; Lado and Wilson, 1994). Managing the mix of new skills resulting from industrial and technological development and traditional skills still relevant to the industry is a major challenge for firms (Fareri and Solinas, 2020).

Research in the field is not only interested in higher skills, but also in the development of soft skills that can be enhanced by innovative processes such as digitalisation (Van Laar et al., 2017; Galati et al., 2019). The appropriate use of digital technologies requires workers to develop a heterogeneous set of soft skills (Chryssolouris et al., 2013; Gorecky et al., 2014; Fonseca et al., 2018). Empirical studies using international competency frameworks for econometric analysis (Frey and Osborne 2017; Arntz et al. 2017; Autor and Dorn 2009; Acemoglu and Autor 2010; MacCrory et al. 2014), data comparison and data linkage (Pryima et al., 2018; Alfonso-Hermelo et al., 2019) suggest a clear link between high skill development and the use of soft skills.

The third reason is related to the perspective of the labour market. Emilia and the automotive industry in particular offer an opportunity to revisit the ongoing debate on the impact of labour market flexibility and rigidity on industry. Italy has been known for its labour market rigidity for a long time (OECD, 1994b). According to Berton et al. (2012), the reason for this is mainly attributed to the Italian legislation on individual dismissals that has been in force since 1970 (Laws 604/1966 and 300/1970). The law stipulates that a company can only dismiss a worker for just cause (such as damage to equipment, fights or violence) or if there is a legitimate reason. Labour market rigidity can cause inefficiency due to high layoff costs, leading to organisational inefficiencies in the production process (Bassanini and Ernst, 2002; Bierhanzl, 2005). At the same time, extremely low turnover limits the ability to effectively allocate workers in the labour market (Rogerson, 1987), resulting in economic inefficiency and low productivity (Elmsekov et al., 1998; Lazear, 1990; Grubb and Wells, 1993; Heckman and Pagés, 2000).

The literature on worker turnover provides a wide range of examples, both theoretical (Bentolila and Bertola, 1990; Bertola, 1990) and empirical (OECD, 2004; Noelke, 2011), of market failures associated with high labour market rigidity, which undoubtedly leads to allocative inefficiency of workers. Another important area of research, led by Acemoglu and Pischke (1998; 1999), questions the long-term effects of rigidity that allow for the development within firms of skills that are appropriate and functional for business activity (Contini and Revelli, 1992; Contini and Trivellato, 2005).

The aim of the essay in this chapter is to reconnect these themes by analysing the labour market in the sector using data from the SILER (Sistema Informativo Lavoro Emilia-Romagna) archive, which contains mandatory company announcements (see Fareri and Solinas, 2020). The essay uses both aggregate data (now available on the Region's website) and microdata for the period 2008-2017 from SILER. The use of the SILER archive in conjunction with ESCO (European Skill/Competence Qualification and Occupation) enables the study of the evolution of labour demand. This highlights the main aspects related to the change in the composition of skills demanded by the local industry.

The paper is structured as follows. Section 2 presents the dataset used for analysis. Section 3 analyses employment duration in the region, first in terms of turnover and then specifically in terms of job duration Section 4 examines labour demand in the region using the SILER source data. Using the ESCO database in conjunction with SILER, the section also discusses changes in the skills demanded by the industry. The last section presents the main conclusions of the paper.

2. Data

This paper presents an analytical examination of the automotive industry in Emilia-Romagna. The analysis is based on data from the regional labour market dataset SILER (Sistema Informativo Lavoro Emilia-Romagna). The dataset includes microdata on individual employment relationships for all companies in the sector from 2008 to 2017. SILER provides a comprehensive overview of hiring, transformation, renewals and firings in the Emilia-Romagna region during the specified period, offering valuable insights into the dynamics of the labour market. SILER's aggregated data for 2022 can be used for a preliminary but essential analysis.

The dataset includes personal information, hiring and termination dates, contract types, Professional qualifications and economic and normative treatment. The dataset analyses 47,466 employment relationships in the automotive industry, which includes car manufacturing and is identified by ATECO 2007 codes ranging from 29.10.00 to 29.32.09. Out of these, 34,048 had been terminated and 13,418 were still active at the end of the period under review.

Section 3 analyses turnover and contract duration to examine the characteristics of the industry at regional level. The focus is on the flexibility of the industry. Subsequently, Section 4 presents an analysis of changes in skills and Professional demand over time. The analysis starts by identifying the most and least in-demand Professions in the automotive labour market. Then, it examines the skills that are most in demand. These skills are closely linked to the organisation of the production process. They are also influenced by emerging trends related to the introduction of new production technologies.

This paper uses a crosswalk analysis between the European Skills, Competences, Qualifications and Occupations (ESCO) database and the skills of the individuals included in each of the SILER observations. ESCO is a dictionary-like structure that describes, identifies and classifies professions, skills and qualifications relevant to the EU labour market, education and training. Each ESCO observation is identified by an ISCO-08 code. Analysing the data at the 5-digit level allows a more precise interpretation of the changes in skills over the period considered. This allows the identification of skills that are currently in higher demand in the regional automotive market. The crosswalk also identifies skills that characterise different professions.

3. The automotive industry in Emilia-Romagna

3.1 Turnover analysis

This section presents an analysis of regional automotive industry turnover between 2008 and 2017, using microdata on individual employment contracts. It provides an overview of trends in regional automotive professions and contracts, and a partial analysis of the current context using ART-ER's 2022 aggregation data. The analysis focuses on activations, firings and net employment changes that have affected the industry in the region, including voluntary departures.

The automotive supply chain in this region requires special attention due to its unique dynamics. The regional automotive industry has seen an 8.4% increase in the number of active firms over the past nine years, from 190 in 2008 to 206 in 2017 (see Table 1). Furthermore, the industry has seen a significant rise in employment, with the number of employees increasing from 13,167 in 2008 to 14,592 in 2017, representing a growth of 9.8%.

Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Companies	190	190	197	199	198	192	198	209	215	206
Employees	13.167	11.583	11.484	11.468	11.100	11.238	12.994	13.139	13.687	14.592
Empoloyees for company	69,30	60,96	58,29	57,63	56,06	58,53	65,63	62,87	63,66	70,83

AWU (Annual work unity)	10.750	10.232	9.883	9.527	9.599	9.633	10.244	11.013	11.678	12.182
Men (AWU)	8.669	8.178	7.949	7.667	7.705	7.731	8.262	8.902	9.441	9.825
Woman (AWU)	2.081	2.053	1.934	1.861	1.894	1.902	1.982	2.111	2.237	2.357
Permanent contract (AWU)	8.786	8.912	8.677	8.226	8.095	8.068	8.408	8.866	9.567	9.777
Fixed-term contract (AWU)	935	737	602	642	719	639	690	712	743	590
Apprenticeship, administered and parasubordinate work (AWU)	1.028	581	604	658	785	926	1.144	1.434	1.368	1.814

Table 1. Automotive companies and employees in Emilia-Romagna

The number of AWUs performed on fixed-term contracts decreased by 37%, while the number of AWUs performed on permanent contracts increased by 11%. However, the most significant change was in apprenticeships, administered and parasubordinate work, which increased significantly by 76% compared with 2008. The dominance of small and medium-sized enterprises is closely linked to the nature of the automotive industry in Emilia-Romagna.

More specifically, the employment dynamics in the automotive industry in Emilia-Romagna between 2008 and 2017 can be delineated into the following four phases (Fig. 1):

- Between 2008 and 2009, there was a decrease in net employment due to a slowdown in hiring rather than an increase in firing. The number of firings decreased by approximately 1,500 during this period. The analysis includes voluntary resignations in the calculation;

- Between 2010 and 2011, there was a negative trend in net employment change. In 2010, there was an improvement in net employment change due to an overall increase in hirings. However, in 2011, the negative trend continued due to an increase in firings, although the number of hirings remained at 2,750;

- Between 2012 and 2016, there was a significant recovery in employment. After reaching a peak in 2011, the number of firings decreased until 2013, followed by an increase in 2014.

Since 2012, however, there has been a significant increase in the number of hires, which has followed a similar trend to that of the number of firings between 2013 and 2016. Finally, since 2014, the levels of hiring and firing have been comparable to those of 2008;

- In 2017, the labour market stabilized with an increase in firings compared to 2016 and a slight decrease in hiring compared to the previous three years. Consequently, there was a small positive change in net employment of 201 units.

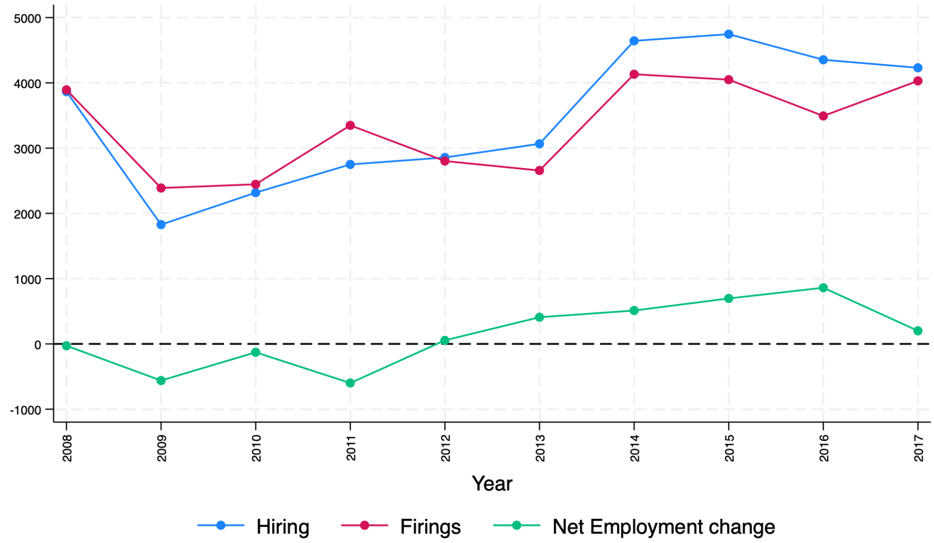
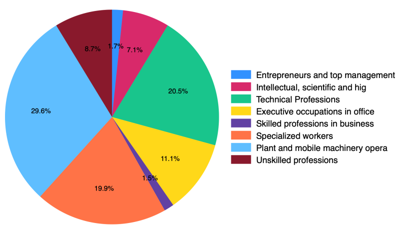
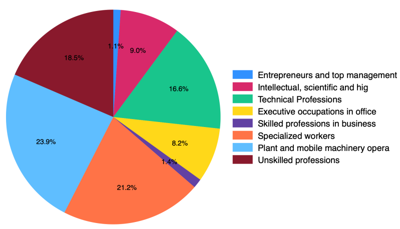
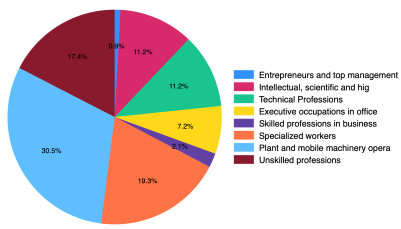


Figure 1. Hiring, firings and net employment change between 2008 and 2017

Below is an analysis of the distribution of hiring in the automotive industry by occupational code CP2021 over three time periods: 2008-2012, 2013-2017, and 2022. The analysis also examines various types of contracts (see Figure 2).

<table>
<tr><td></td><td>2008-2012</td><td>2013-2017</td><td>2022</td></tr>
<tr><td>Occupation</td><td>
</td><td>
</td><td>
</td></tr>
</table>

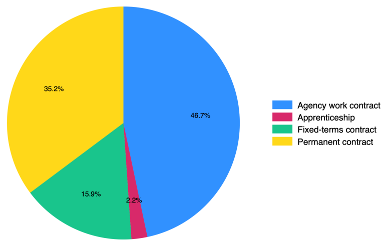
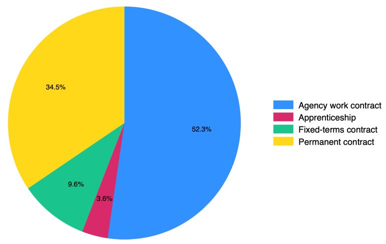
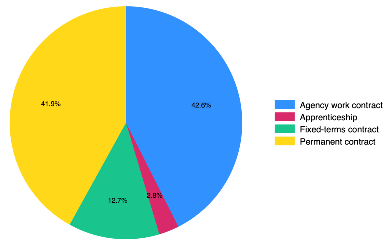
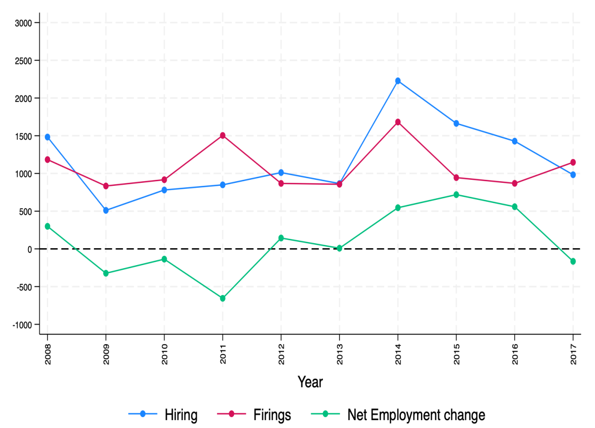
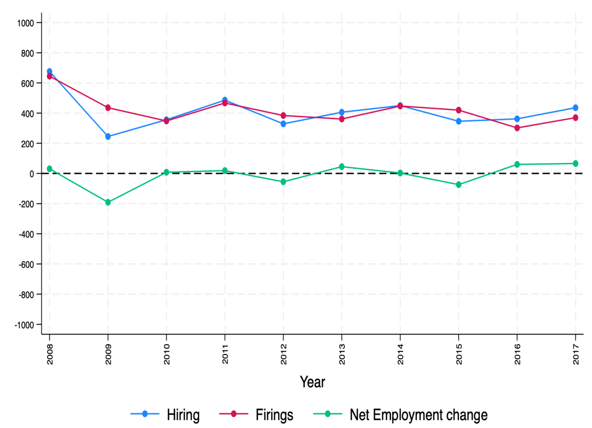
Contract			

Figure 2. Share of Hiring by Occupation and Contract (ISTAT definition)

Between 2008 and 2012, 29.6% of hires in the industry were machinery operators. In contrast, technical professions experienced a significant decline in hiring over the same period. They accounted for 20.5% of hires before 2012, fell to 16.6% between 2013 and 2017, and will decline further to just 11.2% in 2022. The share of executive professions in office has fallen from 11.1% in 2008-2012 to 7.2% in 2022. In contrast, the percentage of scientific and intellectual figures hired in the automotive industry has increased from 7.1% in the first period to 11.2% in 2022. The share of skilled workers hired remains stable, but there is a high share of unskilled workers, which is 17.4% in 2022, slightly lower than the 18.5% recorded between 2013 and 2017.

Analysing the evolution of the most common contracts used in the automotive industry in Emilia Romagna over the three periods shows a slightly different pattern. The share of permanent contracts increased from 35.2% in 2008-2012 to 41.9% in 2022, while the share of agency works contracts decreased from 46.7% in the first period to 42.6% in 2022, after reaching a peak of 52.3% in the 2013-2017 period. The percentage of fixed-term contracts decreased from 15.9% during 2008-2012 to 12.7% in 2022, while apprenticeship contracts remained stable.

Permanent contract	Fixed-terms contract
	

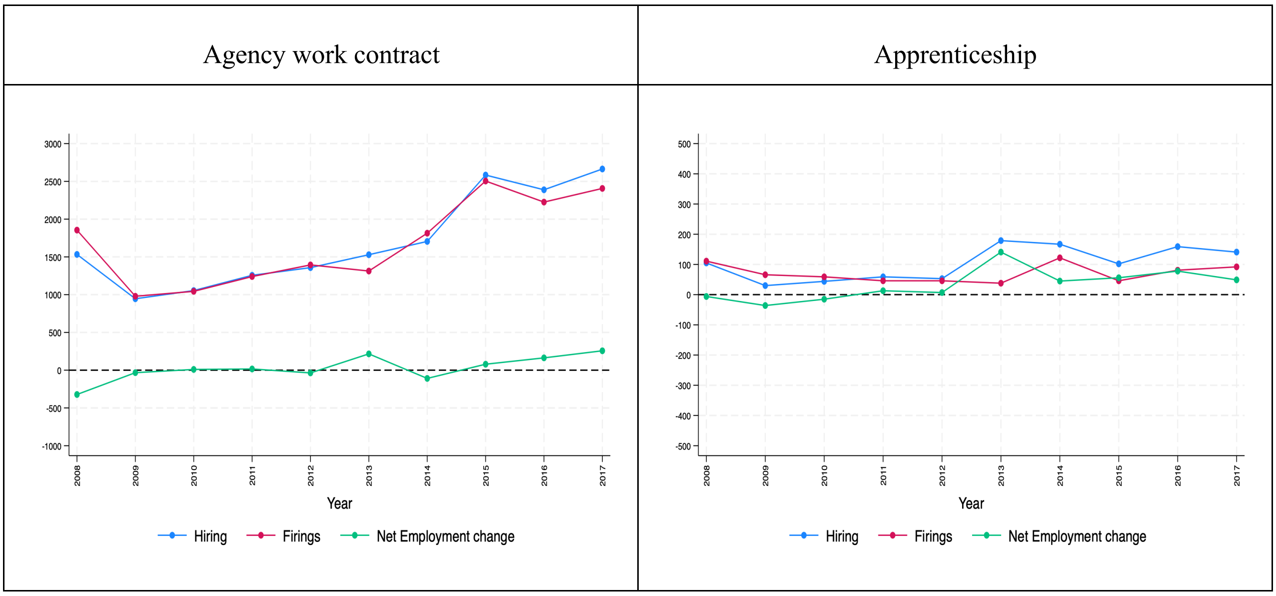


Figure 3. Trend of hiring, firings and net employment change by contract (ISTAT definition)

As shown in Figure 3, looking at the dynamics of permanent contracts between 2008 and 2017, the number of activated and terminated contracts fluctuated throughout the period. Following the financial crisis, it appears that many were terminated between 2008 and 2011. However, in 2012 the trend reversed and there was an increase in the number of activations. In 2014, the number of permanent contract activations was over 2000. However, in 2017, the number of firings exceeded the number of activations. The net employment change over the period was strongly negative in 2011, reaching -655, but became significantly positive between 2014 and 2016. In 2015, the net employment change was 719, in line with the positive trend in permanent employment activations that characterised the industry.

Figure 3 displays the trends in hiring, firings and net employment changes for fixed-term contracts from 2008 to 2017. In 2009, there was a significant drop in hiring due to the financial crisis, followed by a rapid recovery. Since 2010, the number of fixed-term contracts has remained steady at approximately 400 per year. The number of firings has remained similar to the number of activations, resulting in an almost zero balance at the end of each year. Since 2008, temporary agency contracts have shown a consistent trend of hiring and firing, following an initial negative balance of -322. The net change in employment was - 322 in 2008 and then increased to a positive 216 in 2013. During this period, apprenticeship contracts have been of limited importance and have shown a consistent trend. Since 2013, there has been a significant increase in the number of activated apprenticeships contracts each year. However, the net change in employment has always remained positive and has never exceeded 100.

Analysing personal traits of the workforce in the automotive industry of the region between 2008 and 2017, the trends are particularly useful in understanding the evolution of the industry.

Figure 4 shows an increasing trend in the employment of men over the years, with almost 4,000 activations recorded for men in 2015. for men in 2015. Throughout the period analysed, the share of activations for women remained constant.

Figure 4. Trend of hiring and firings by personal characteristics

The data are similar when the sample is split between foreign and Italian workers. The data show that the hiring trend of Italian workers has increased since the 2008 crash. On the other hand, the hiring of foreign workers has remained constant in recent years and has not yet reached pre-crisis levels. Since 2012, we have seen an increase in hiring graduates. Despite a slight dip in 2016, the hiring of graduate workers has increased by around 50%. These data are consistent with an increase in demand for skills in the industry, in line with recent technological advances. This trend is explored further in Section 4, which analyses skills and professions. The number of specialised workers is increasing, but technical work remains crucial in the industry.

Further assumptions can be made by analysing skills and the corresponding net change in employment.

Despite the economic trend and the impact of the economic-financial crisis, the dominant issue is the prevalence of contractual forms that offer little protection for workers and are associated with short durations. Even in advanced regions, such as Emilia-Romagna, industrial recruitment during the decade was concentrated on contracts with high turnover rates, especially for vulnerable groups. Let us look at the duration of employment contracts before concluding on this aspect.

3.2 Duration model

This section focuses on the duration of contracts in industry between 2008 and 2017. Using the ISTAT CP2021 classification, the study analyses the differences in contract duration for each profession and examines these differences for each type of contract and job characteristics. It then compares the contract duration strategies of two major luxury car manufacturers, Ferrari SpA and Lamborghini SpA, and presents a duration model for analysing contract duration in the industry.

Duration analysis is a central topic in econometrics. Since the early 1980s, the empirical analysis of duration variables has become widespread. The application of duration models in labour economics includes the analysis of the duration of unemployment (Devine and Kiefer, 1991), the duration of strikes (Kennan, 1985) and the duration of training (Bonnal et al., 1997). The aim of duration models is to determine the length of time that passes from one initial situation to the next. This illustrates the central role that dynamic models have now assumed in the economic literature (Van den Berg, 2000).

Table 2 shows the correlation between the ISTAT profession code of the employee (CP2011) and the average length of the contract. As expected, Entrepreneurs and Top Managers tend to have longer contracts on average compared to other employees. Plant and mobile machinery operators tended to have longer contracts on average, whereas unskilled and professional workers had shorter contracts. The average duration of a contract for those employed in technical and clerical professions is 1131 days.

Profession (CP2021)	Average contract duration (days)
1 - Entrepreneurs and top management	1904

2 - Intellectual, scientific and highly specialized professions	1021
3 - Technical Professions	1548
4 - Executive occupations in office work	1476
5 - Skilled professions in business and services	1228
6 - Specialized workers	1086
7 - Plant and mobile machinery operators	1131
8 - Unskilled professions	1002

Table 2. Average contract duration by occupation between 2008 and 2017

Table 3 shows the average duration of each type of contract in the automotive industry in Emilia-Romagna.

Contract	Average contract duration (days)
Permanent Contract	2936
Fixed-term Contract	339
Apprenticeship	567
Parasubordinate Contract	427
Agency Work Contract	139

Table 3. Average contract duration by Contract between 2008 and 2017

The average duration of a permanent job is 2936 days, while the average duration of agency work is around 139 days. Fixed-term contracts have an average duration of only 339 days and apprenticeships do not exceed 567 days on average. Overall, there is clearly a problem with the short duration of contracts such as agency contracts that predominate in the industry.

The table below presents employment data for Ferrari and Lamborghini, two major final production brands in the region. From 2008 to 2017, Ferrari accounted for around 8,000 workers and Lamborghini for around 6,000 workers. Table 4 displays the correlation between the CP2011 profession code and the average contract duration for both brands. It presents the average contract length and the percentage of employees in each profession.

Profession (CP2021)	Ferrari S.p.A		Lamborghini S.p.A	
	Average contract duration (days)	%	Average contract duration (days)	%
1 - Entrepreneurs and top management	977	2%	205	2%
2 - Intellectual, scientific and highly specialized professions	723	9%	428	12%
3 - Technical Professions	558	20%	316	14%
4 - Executive occupations in office work	651	5%	259	7%
5 - Skilled professions in business and services	308	1%	161	3%
6 - Specialized workers	256	10%	116	34%
7 - Plant and mobile machinery operators	207	25%	328	18%
8 - Unskilled professions	142	28%	108	10%

Table 4. Average contract duration by occupation between 2008 and 2017, Ferrari vs Lamborghini

The duration of contracts at Ferrari is significantly longer than at Lamborghini, except for plant and mobile machinery operators who have longer contracts at Lamborghini. However, the duration of contracts at Ferrari is also significantly shorter than industry averages in the region. At Ferrari, the proportion of unskilled workers is significantly higher, at 28%, compared to Lamborghini's 10%. Conversely, skilled workers make up the majority of Lamborghini's workforce, accounting for 34%.

Table 5 highlights the high proportion of agency work contracts at both Ferrari (54%) and Lamborghini (61%). The average duration of these contracts is remarkably low, at 174 days for

Ferrari and 115 days for Lamborghini, which is below the industry average. This emphasizes the prevalence of short contracts, particularly in large brands such as Ferrari and Lamborghini.

Contract	Ferrari S.p.A		Lamborghini S.p.A	
	Average contract duration (days)	% used (Overall, all contracts)	Average contract duration (days)	% used (Overall, all contracts)
Permanent Contract	1147	42%	668	31%
Fixed-term Contract	333	4%	69	5%
Apprenticeship	-	-	928	3%
Parasubordinate Contract	-	-	-	-
Agency Work Contract	174	54%	115	61%

Table 5. Average contract duration by contract between 2008 and 2017, Ferrari vs Lamborghini

Using the Kaplan-Meier estimator, Figure 5 presents duration models analysing the average duration of employment contracts between 2008 and 2017. The analysis is based on contract types, professional codes, gender, nationality and educational qualifications. The first aspect of the figure concerns the stability of contracts, specifically the duration of permanent contracts. The automotive industry is characterised by the prevalence of short-term contracts, such as agency work contracts. According to the Kaplan-Meier estimator, over 95% of agency contracts have a short duration. In contrast, apprenticeships and permanent contracts have longer average durations. The second section emphasises the significance of technical and managerial professions concerning contract duration.

The analysis by gender and nationality shows that men and women have similar contract durations, but there is a significant difference between Italian and foreign workers. In particular, foreign women have very short-term contracts in the industry. The last section shows that university graduates tend to have fewer short-term contracts. For example, the data show that 20% of university graduates employed in the industry have had a contract of 1000 or more working days, while only about 10% of non-graduates have.

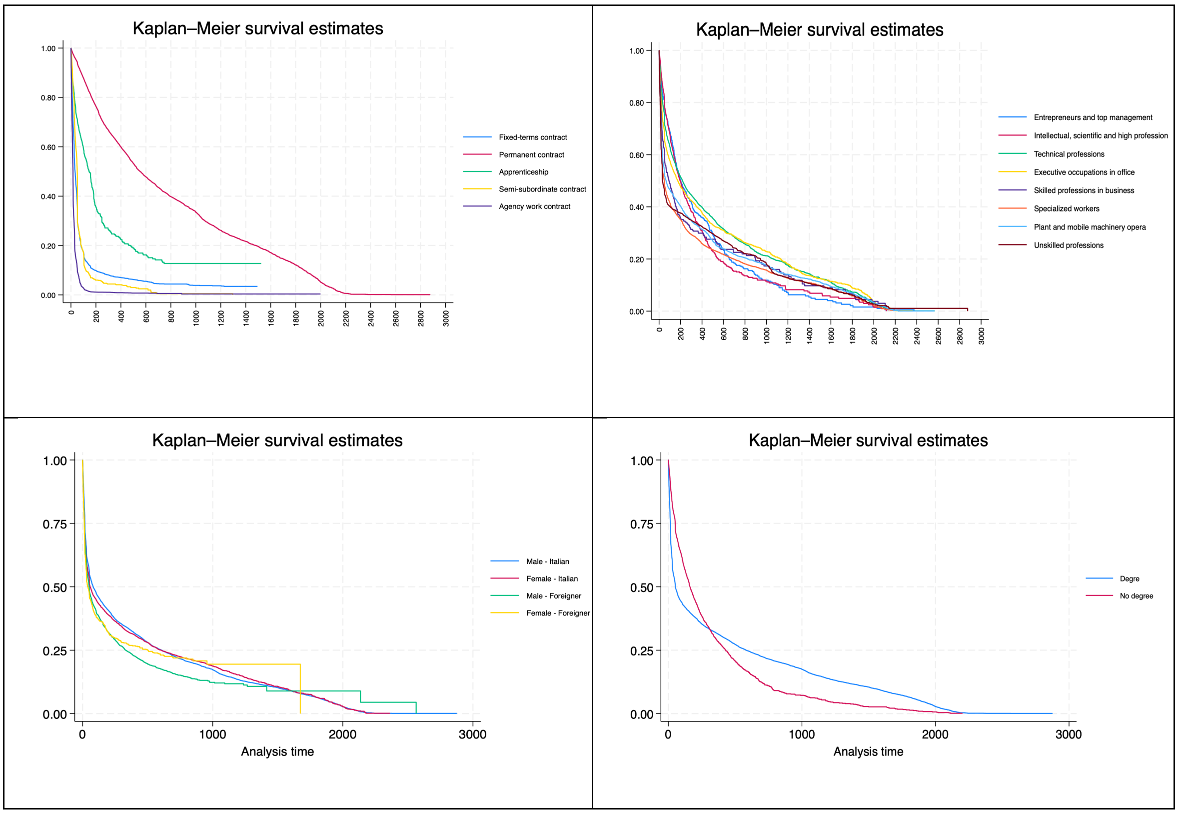


Figure 5. Duration analysis using the Kaplan-Meier estimator for some categorical variables between 2008 and 2017, in days

The model shows that in recent years there has been an increase in the use of contracts leading to short-term employment and high turnover, although the impact of this trend varies across groups of workers. It is important to note that this kind of flexibilization is no longer a marginal phenomenon, even in the prosperous regions with the most advanced firms. There is no evidence to suggest that labour remains rigid.

Importantly, this applies not only to small subcontractors, but also to prestigious manufacturers. Ferrari and Lamborghini, for example, have implemented highly flexible forms of contract, despite having different industrial relations models (Russo et al., 2018; Fiorani and Simonazzi, 2018). There are a number of different realities behind short-term jobs, of course. Sometimes companies and workers even have agreements to pursue forms of tax avoidance. It is also difficult to monitor these aspects using flow data based on mandatory reporting by companies. Surely, in the automotive industry there is a widespread phenomenon of short-term employment contracts, which is dangerous from a long-term perspective. This policy can lead to disinvestment in human capital by both companies and workers. It can also lead to labour markets where precariousness and low pay are the norm, undermining sound industrial relations. In order to complete the analysis of the labour market in the sector, the following sections have a focus on occupations and skills.

4 Professions and skills

4.1 Professions most in demand

This section uses a simple survey technique to identify the ten occupations and skills for which there has been the greatest increase in demand and the ten for which there has been the greatest decrease in demand over the period under review, from among the hundreds of options classified by Siler (and Istat) (Fareri and Solinas, 2020). The result obtained is a first approximation that provides an insight into the trends in the sector, but it is important to note that this is a subjective assessment. As mentioned above, the period considered is the decade from 2008 to 2017.

Table 6 analyses the top ten professions with a more positive net employment change at the end of 2017 in the regional automotive industry. Mechanical engineers stand out with 795, followed by motor vehicle mechanics and repairers with 369 and technical draftsmen with 343. Other key professions include general clerical workers (339) and chemical engineers (94).

2008-2017	
Profession most in demand	Net employment change
Mechanical engineers	795
Motor vehicle mechanics and repairers	369
Draughtspersons	343
General office clerks	339
Assemblers not elsewhere classified	194
Real estate agents and property managers	171
Stock clerks	134
Administrative and executive secretaries	120
Mechanical engineering technicians	108
Chemical engineers	94

Table 6. Occupation most in demand in Emilia-Romagna’s industry between 2008-2017

During the crisis, positive changes are rare even among the most in-demand occupations. In the second period (2013-17), there was a significant growth in demand for mechanical engineers. This was accompanied by an increase in demand for a variety of skilled workers, such as motor vehicle mechanics and repairers, hand packers and mechanical assemblers (see Table 7).

2008-2012		2013-2017	
Professions most in demand	Net employment change	Professions most in demand	Net employment change
Mechanical engineers	111	Hand packers	776
General office clerks	88	Mechanical engineers	684
Upholsterers and related workers	35	Motor vehicle mechanics and repairers	512
Real estate agents and property managers	32	Mechanical machinery assemblers	340
Product and garment designers	20	Draughtspersons	340
Technical and medical sales professionals (excluding ICT)	18	Metal polishers, wheel grinders and tool sharpeners	305
Construction supervisors	18	General office clerks	251
Electrical line installers and repairers	17	Assemblers not elsewhere classified	204
Statistical, mathematical and related associate professionals	17	Stock clerks	198
Geologists and geophysicists	17	Welders and flame cutters	152

Table 7. Professions most in demand in Emilia-Romagna's automotive industry between 2008-2017

Through the analysis of the data from the SILER update until 2022, it is possible to determine the total number of activations for each professional activity in the automotive industry and the percentage change for each relevant profession in comparison with 2017. For instance, the number of mechanical machine assemblers has increased by 485% compared to

2017, while the number of mechanical engineering technicians has increased by 281%. Mechanical engineering continues to grow. It shows a positive trend of 93% compared to the previous period (see Table 8).

2022		
Professions most in demand	Hirings	Variation 2017-2022(%)
Hand packers	625	-31%
Mechanical machinery assemblers	538	485%
Motor vehicle mechanics and repairers	434	-5%
Mechanical engineers	386	93%
Metal polishers, wheel grinders and tool sharpeners	236	-15%
Odd job persons	175	113%
Transport clerks	173	85%
Mechanical engineering technicians	141	281%
Shop sales assistants	91	86%
Administrative and executive secretaries	47	-32%

Table 8. Hiring in Emilia-Romagna's automotive industry in 2022

4.2 Professions less in demand

This section provides a brief analysis of the professions with the most negative net employment change over the period considered. Table 9 shows the professions with the most negative net employment change between 2008 and 2017. Noteworthy was the fact that some professions like ‹‹administrative secretaries›› (-238), ‹‹supervisors›› (-227) and ‹‹tool and die makers›› (-90) had consistently negative employment changes over the period.

2008-2017	
Professions less in demand	Net employment change
Secretaries (general)	-238
Office supervisors	-227
Toolmakers and related workers	-90
Civil engineering technicians	-75
Electrical and electronic equipment assemblers	-61
Metal processing plant operators	-43
Spray painters and varnishers	-37
Valuers and loss assessors	-34
Data entry clerks	-27
Handicraft workers in textile, leather and related materials	-24

Table 9. Professions less in demand in Emilia-Romagna's industry between 2008-2017

Table 10 stratifies the results by period and distinguishes between the professions that experienced the most negative net change in employment between 2008 and 2012 and the professions that experienced the most negative net change in employment between 2013 and 2017.

2008-2012		2013-2017	
Professions less in demand	Net employment change	Occupation Less in Demand	Net employment change
Hand packers	-695	Secretaries (general)	-90
Mechanical machinery assemblers	-317	Office supervisors	-47
Metal polishers, wheel grinders and tool sharpeners	-233	Metal moulders and coremakers	-30

Office supervisors	-180	Civil engineering technicians	-22
Metal processing plant operators	-163	Aircraft engine mechanics and repairers	-22
Secretaries (general)	-148	Film, stage and related directors and producers	-5
Motor vehicle mechanics and repairers	-143	Sweepers and related labourers	-4
Toolmakers and related workers	-87	Electrical engineering technicians	-4
Welders and flamecutters	-86	Payroll clerks	-4
Stock clerks	-64	Elementary workers not elsewhere classified	-4

Table 10. Professions less in demand in Emilia-Romagna's automotive industry between 2008-2017

Since 2013, certain professions, including civil engineers, have exhibited a negative trend. In contrast, motor vehicle repairers, who experienced a negative net employment change before 2012, appear to be recovering in the latter period.

4.3 Skills most in demand

The following sections expand on the ESCO jobs previously studied and highlight emerging trends in the primary skills demand. ESCO provides a comprehensive list of skills associated with different professions. This list is regularly updated to reflect changes in the labour market. This study aims to analyse the evolution of specific skills, identifying those that are growing in importance and demand, as well as those that are declining in importance and less desirable to firms in the industry over time.

This section analyses the skills that showed a positive net change in employment throughout the period. This indicates an increase in demand from enterprises in the industry. In particular, it focuses on those skills that consistently showed a positive net change in employment throughout the period. Table 11 presents a comprehensive analysis of the period between 2008 and 2017, outlining the most in-demand skills in the automotive industry.

2008-2017	
Skill most in demand	Net employment change
Provide membership service	211
Read standard blueprints	152
Apply GMP	133
Liaise with advertising agencies	126
Manage staff	96
Data mining	95
Adhere to organisational guidelines	88
Wear appropriate protective gear	85
Manage budgets	85
Liaise with managers	78

Table 11. Skill most in demand in Emilia-Romagna's automotive industry between 2008-2017

******

The most in-demand skills include ‹‹Providing membership services›› (211), ‹‹Reading standard blueprints›› (152) and ‹‹Applying GMP›› (133).

Table 12 presents the most requested skills for the periods 2008-2012 and 2013-2017, highlighting the main similarities and differences. Providing membership services (85) was the most in-demand skill between 2008 and 2012, while ‹‹Operating CNC laser cutting machine›› (215) had a more positive net employment change in the subsequent period, after a negative employment change in the first period. Between 2013 and 2017, skills such as ‹‹Applying GMP›› (160) and ‹‹Data mining›› (84) became more important.

2008-2012		2013-2017	
Skill most in demand	Net employment change	Skill most in demand	Net employment change
Provide membership service	85	Tend CNC laser cutting machine	215

Wear appropriate protective gear	70	Apply GMP	160
Liaise with advertising agencies	41	Read standard blueprints	130
Guarantee customer satisfaction	40	Provide membership service	126
Provide customer follow-up services	40	Manage staff	98
Ensure compliance with legal requirements	39	Adhere to organisational guidelines	89
Perform scientific research	39	Manage budgets	88
Issue sales invoices	38	Carry out stock rotation	88
Maintain store cleanliness	37	Liaise with advertising agencies	85
Organise storage facilities	37	Data mining	84

Table 12. Skill most in demand in Emilia-Romagna's automotive industry between 2008-2017

The demand mix is complex, requiring traditional industry skills as well as new ones related to service development, machinery and process control, and information flow management. Aggregate figures for 2022 show similar trends (see Table 13). Of particular note is the increase in demand for skills such as ‹‹analysing a company's financial performance›› (+427%) and ‹‹monitor automated machinery›› (+248%).

2022		
Skill most in demand	Hiring	Trend between 2017 and 2022
Pack goods	625	-31%
Metal smoothing technologies	236	-14%

Advise on machinery malfunctions	87	200%
Monitor automated machines	87	248%
Train employees	85	143%
Analyse financial performance of a company	58	427%
Manage budgets	42	-29%
Recruit employees	42	-21%
Employment law	42	-18%
Ensure correct goods labelling	15	-70%

Table 13. Hiring in Emilia-Romagna's automotive industry in 2022

4.4 Skills less in demand

Table 14 shows the net change in employment for specific skills over the period considered. This indicates that these skills were considered to be less necessary in the production process. The skills with the most negative net change in employment were ‹‹Packaging goods›› with a change in employment of -699, ‹‹Performing routine office activities›› with a change in employment of -129 and ‹‹Metal smoothing technologies›› and ‹‹Spraying & varnishing›› were considered less necessary by the region's automotive industry, resulting in employment changes of -99 and -45 respectively. Some of these trends clearly show the impact of advances and process automation in manufacturing, warehousing and office management.

2008-2017	
Skill less in demand	Net employment change
Pack goods	-699
Perform office routine activities	-129
Conduct research interview	-117
Metal smoothing technologies	-99

Mechanical components of vehicles	-70
Apply spraying techniques	-45
Assist students in their learning	-32
Provide lesson materials	-30
Assess students	-30
Manage resources for educational purposes	-29

Table 14. Skill less in demand in Emilia-Romagna's industry between 2008-2017

It is worth noting that activities and skills typically associated with vocational training are also decreasing in importance. It is unclear whether this is due to changes in training technologies or simply a reduction in the resources allocated to training. Several tasks experienced a decline in employment when comparing the two periods. In particular, between 2008 and 2012, abilities such as ‹‹Packing goods›› (-651) and ‹‹Operating a CNC laser cutting machine›› (-223) experienced a particularly negative net change. In the subsequent period, professions such as ‹‹Carrying out routine office activities›› (-41) and ‹‹Making sales calls›› (-38) also showed a decline. The reorganization of intermediate and finished goods warehouses resulted in a negative net change in employment for activities such as ‹‹packing of goods›› in both periods analysed. This is shown in Table 15.

2008-2012		2013-2017	
Skill less in demand	Net employment change	Skill less in demand	Net employment change
Pack goods	-651	Pack goods	-48
Tend CNC laser cutting machine	-223	Perform office routine activities	-41
Mechanical components of vehicles	-136	Sales argumentation	-38
Metal smoothing technologies	-135	Demonstrate products' features	-38
Conduct research interview	-92	Provide customer follow-up services	-38

Perform office routine activities	-88	Issue sales invoices	-38
Follow safety procedures when working at heights	-70	Carry out order intake	-37
Rigging terminology	-38	Organise storage facilities	-36
Apply spraying techniques	-29	Carry out active selling	-36
Apply GMP	-27	Organise product display	-36

Table 15. Skill less in demand in Emilia-Romagna's automotive industry between 2008-2017

4.5 Digital and green skills

In conclusion, this analysis aims to identify trends in the green and digital transition in industry based on SILER-ESCO micro data. This section presents the main findings for the regional automotive industry in terms of trends over time for skills related to the green and digital skills. The ESCO database was used to define green and digital skills by linking professions to ESCO.

Figure 6 shows the trends in hiring, firings, and net employment change for workers with skills related to the green industry, as defined by ESCO.

Green workers	Digital workers

Figure 6. Employment for green and digital workers between 2008 and 2017

There was a strong growth trend in green-related professions from the beginning of the period, but the trends remained constant from 2012 onwards, with no significant peaks. In the area of digital skills, it is crucial to recruit highly skilled workers to cope with the constant technological development. The European Union has set a target for 80% of citizens aged 16-74 to have basic digital skills by 2030. This underlines the importance of such skills. Currently, only 53.9% of citizens will have these skills in 2021. In Italy, the percentage of citizens between the ages of 16 and 74 with basic digital skills is even lower at 45.7% (ISTAT, 2023).

Figure 7 illustrates the hiring balances of workers associated with the green economy and sustainable economic development on a regional basis. The provinces of Modena and Bologna show particularly positive trends between 2008 and 2017. The trend is also strong in the province of Bologna. Automotive firms seem to be particularly sensitive to environmental sustainability issues. Regionally, the employment of workers with high digital skills is particularly positive in the provinces of Modena and Bologna. However, the trend is also strongly on the increase in the province of Ravenna. Over the period considered, two provinces experienced an increase in the number of workers with digital skills in the automotive industry. These provinces absorb a larger share of such workers. However, while the number of workers with digital skills is on the rise, there is still a need for technicians to drive the industry forward in traditional ways. The automotive industry is heavily influenced by innovation but remains largely tied to manufacturing traditions.

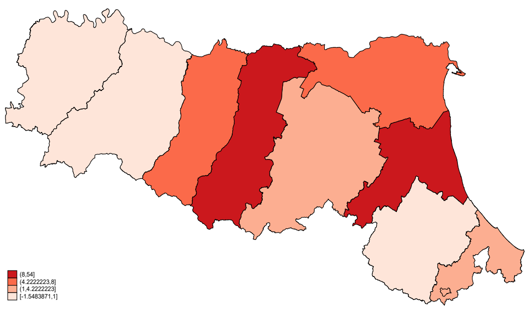
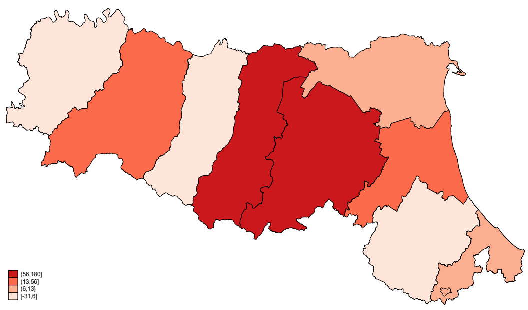
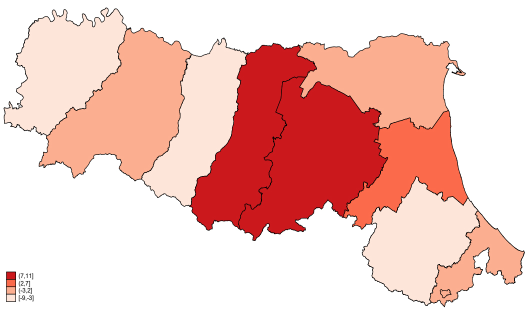
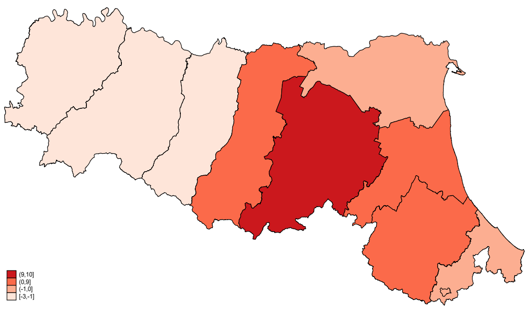
	Net employment change	Trend (%)
Digital workers		
Green workers		

Figure 7. Balance and trend for green and digital workers between 2008 and 2017

A more complete understanding of these processes would require more recent data, which are not available at the moment. However, the period 2008-2017 already shows the beginning of significant changes.

5. Final remarks

This chapter presents a flow analysis of the labour market in the automotive industry in Emilia-Romagna, based on micro-data on mandatory declarations provided by the Sistema Informativo Lavoro Emilia-Romagna (SILER). The micro data are available for the period 2008-2017 and in aggregated form for the year 2022. The main findings relate to patterns of employee turnover, length of employment and shifts in demand for specific occupations and skills. By using the SILER dataset linked to the ESCO skills and professions database, we identified a group of professions that experienced a positive net change in employment between hiring and firing during the period under review. The identification of the most in-demand professions in the industry highlights the evolving skill needs of enterprises, driven by the need to integrate workers capable of performing the functions required by the current production process.

The results are only partially consistent with the current literature on digitalisation from the pioneering work of Frey and Osborne (2017) and Autor (2009). There is also evidence of the emergence of new occupations and tasks in relation to the management of automated processes and information systems. In addition, there is a growing demand for professions and skills that require a high level of technical expertise but are still in line with traditional mechanical occupations and tasks. These include roles such as mechanical engineers, motor vehicle mechanics and repairers, and draftsmen. The demand for these professions has shown a positive trend over time.

In contrast, the number of administrative workers is decreasing significantly. This is particularly relevant as management processes evolve with new technologies that simplify accounting and business administration. There seems to be a decreasing demand for clerical workers in the domestic automotive industry, while there is an increasing demand for administrative functions related to safety issues and managing personnel contracts. These trends align with previous research on digitalisation and studies specific to the automotive industry (Mencarelli and Mereu, 2021). This raises questions about the appropriateness of the entire local education system (from vocational and technical schools to tertiary education).

Contrary to most studies on the digital transition in Emilia-Romagna (for instance, Fareri and Solinas, 2021), there is no clear manifestation of a demand for soft skills. It is unclear whether this is due to the inadequacy of classifying jobs and skills to capture these changes, or to the specificities of local production. This is an important issue that requires further research.

The analysis of the labour market in the automotive sector has revealed a second remarkable finding: the short duration of the employment relationship. The data on contract duration shows that the automotive industry extensively uses agency work contracts, which exceed 50% for large premium companies, as observed in the analysis of Ferrari and Lamborghini. The average duration of the agency works contracts offered is 139 days. It is worth noting that temporary contracts with limited durations often result in reduced legal protections for workers.

It is important to underline that the data on mandatory declarations only reflect changes in employment and jobs and not the distribution of the duration of employment within the employed population. Despite this limitation, the analysis covers a significant number of jobs over a long period of time. It is unlikely that these are marginal adjustments due to numerical flexibility. A balance between flexibility and stability is important to maintain motivation and commitment. A low degree of flexibility in the labour market can be just as inefficient as a high degree of flexibility. Constant job changes and fragmented careers can limit the future sustainability of industry by reducing investment in workers and enterprises, leading to a decline in productivity and competitiveness of firms. Jacob Mincer, a major figure in labour economics, has argued that short tenure hinders the formation of human capital by reducing the effectiveness of learning and on-the-job training processes. It is noteworthy that this phenomenon is significant in a region with firms and enterprises that have a long manufacturing history.

References

ANFIA (2023), Osservatorio sulla componentistica automotive italiana e sui servizi per la mobilità. ANFIA, Torino.

Acemoglu, D., and Pischke, J. S. (1998). Why do firms train? Theory and evidence. *The Quarterly Journal of Economics*, *113*(1), 79-119.

Acemoglu, D., and Pischke, J. S. (1999). The structure of wages and investment in general training. *Journal of Political Economy*, *107*(3), 539-572.

Acemoglu, D., and Autor, D. (2011). Skills, tasks and technologies: Implications for employment and earnings. In *Handbook of Labor Economics, 4,* 1043-1171, Elsevier.

Alfonso-Hermelo, D., Langlais, P., and Bourg, L. (2019). Automatically learning a human-resource ontology from professional social-network data. In *Advances in Artificial Intelligence: 32nd Canadian Conference on Artificial Intelligence, Canadian AI 2019,* *Kingston, ON, Canada, May 28–31, 2019, 32,* 132-145, Springer International Publishing.

Arntz, M., Gregory, T., and Zierahn, U. (2017). Revisiting the risk of automation. *Economics Letters*, *159*, 157-160.

Attewell, P. (1992). Technology diffusion and organizational learning: The case of business computing. *Organization Science*, *3*(1), 1-19.

Autor, D., and Dorn, D. (2009). This job is "getting old": measuring changes in job opportunities using occupational age structure. *American Economic Review*, *99*(2), 45-51.

Barney, J. (1991). Special theory forum the resource-based model of the firm: origins, implications, and prospects. *Journal of Management*, *17*(1), 97-98.

Bassanini, A., and Ernst, E. (2002). Labour market institutions, product market regulation, and innovation: cross-country evidence. *OECD Economics Department Working Papers, 316*, OECD.

Becker, B., and Gerhart, B. (1996). The impact of human resource management on organizational performance: Progress and prospects. *Academy of Management Journal*, *39*(4), 779-801.

Bentolila, S., and Bertola, G. (1990). Firing costs and labour demand: how bad is eurosclerosis?. *The Review of Economic Studies*, *57*(3), 381-402.

Bertola, G. (1990). Job security, employment and wages.*European Economic Review*,*34*(4), 851-879.

Berton, F., Richiardi, M., and Sacchi, S. (2012). The political economy of work security and flexibility. Italy in comparative perspective. Policy Press, Bristol.

Bierhanzl, E. (2005). Lessons from America. *Economic Affairs*, *25*(3), 17-23.

Bonnal, L., Fougère, D., & Sérandon, A. (1997). Evaluating the impact of French employment policies on individual labour market histories. *The Review of Economic Studies, 64*(4), 683-713.

Chryssolouris, G. (2013). Manufacturing systems: theory and practice. Springer Science and Business Media.

Contini, B., and Revelli, R. (1992). Imprese, occupazione e retribuzioni al microscopio: studi sull'economia italiana alla luce delle fonti statistiche INPS. Il Mulino, Bologna.

Contini, B., and Trivellato, U. (2005). Eppur si muove: Dinamiche e persistenze nel mercato del lavoro italiano. Il Mulino, Bologna.

Devine, T. J., & Kiefer, N. M. (1991). Empirical labor economics: The search approach. Oxford University Press, USA.

Elmsekov, J., Martin, J. P., and Scarpetta, S. (1998). Key lessons for labour market reforms: evidence from OECD countries' experience. *Swedish Economic Policy Review*, *5*(2), 205-252.

Fareri, S., and Solinas, G. (2021). Who rises and who drops? New technologies, workers, and skills. The case of a developed region, *Sinappsi – Connecting research and public policies*, anno XI, n. 2, 2021, 90-113

Fiorani G. and Simonazzi A. (2017), Two types of labor relations in practice: Ferrari and Lamborghini (mimeo).

Fonseca, D., Conde, M. Á., and García-Peñalvo, F. J. (2018). Improving the information society skills: Is knowledge accessible for all? *Universal Access in the Information Society*, *17*(2), 229-245.

Frey, C. B., and Osborne, M. A. (2017). The future of employment: How susceptible are jobs to computerisation?. *Technological Forecasting and Social Change*, *114*, 254-280.

Fulmer, I. S., and Ployhart, R. E. (2014). Our most important asset: a multidisciplinary/multilevel review of human capital valuation for research and practice. *Journal of Management*, *40*(1), 161-192.

Galati, F., and Bigliardi, B. (2019). Industry 4.0: Emerging themes and future research avenues using a text mining approach. *Computers in Industry*, *109*, 100-113.

Goldin, C., and Katz, L. F. (1998). The origins of technology-skill complementarity. *The Quarterly Journal of Economics*, *113*(3), 693-732.

Gorecky, D., Schmitt, M., Loskyll, M., and Zühlke, D. (2014). Human-machine-interaction in the industry 4.0 era. In *2014 12th IEEE International Conference on Industrial Informatics,* 289-294.

Grillitsch, M., Asheim, B., and Trippl, M. (2018). Unrelated knowledge combinations: The unexplored potential for regional industrial path development. *Cambridge Journal of Regions, Economy and Society*, *11*(2), 257-274.

Grubb, D., and Wells, W. (1993). Employment regulation and patterns of work in EC countries. *OECD Economic studies*, 7-7.

Heckman, J. J., and Pagés, C. (2000). The cost of job security regulation: Evidence from Latin American labor markets.

ISTAT (2023). Rapporto annuale 2023. La situazione del Paese. Roma.

Kennan, J. (1985). The duration of contract strikes in US manufacturing. *Journal of Econometrics, 28*(1), 5-28.

Lado, A. A., and Wilson, M. C. (1994). Human resource systems and sustained competitive advantage: A competency-based perspective. *Academy of Management Review*, *19*(4), 699-727.

Lazear, E. P. (1990). Job security provisions and employment. *The Quarterly Journal of Economics*, *105*(3), 699-726.

MacCrory, F., Westerman, G., Alhammadi, Y., and Brynjolfsson, E. (2014). Racing with and against the machine: Changes in occupational skill composition in an era of rapid technological advance.

Mencarelli, E. and Mereu, M.G. (2021). Anticipazione dei fabbisogni professionali nel settore dell'automotive. INAPP, Roma.

Noelke, C. (2011). The consequences of employment protection legislation for the youth labour market. *Arbeitspapiere – Working Papers, 144.*

OECD. (1994). The OECD Jobs Study: Evidence and Explanations. Paris, OECD.

OECD. (2004). The OECD principles of corporate governance. *Contaduría y Administración, 216.*

Pianta, M. (2018). Technology and employment: twelve stylised facts for the digital age. *The Indian Journal of Labour Economics*, *61*, 189-225.

Pryima, S., Dayong, Y., Anishenko, O., Petrushenko, Y., and Vorontsova, A. (2018). Lifelong learning progress monitoring as a tool for local development management. *Problems and Perspectives in Management*, *16*(3), 1-13.

Rogerson, R. (1987). An equilibrium model of industrial reallocation. *Journal of Political Economy*, *95*(4), 824-834.

Russo, M. (2018). L'Industria automotive in Emilia-Romagna, Osservatorio sulla componentistica automotive italiana. ANFIA, Torino.

Russo M., Pavone, P. and Cetrulo, A. (2018). Conflict and partecipation in bargaining. The Lamborghini Case. *Economia e Lavoro*, anno LIII, 53-74.

Russo, M., and Pentucci, P. P. (2019). La filiera della componentistica automotive in Emilia-Romagna. In *Osservatorio sulla componentistica automotive italiana 2019, 4*, 143-161. Ca'Foscari.

Van Laar, E., Van Deursen, A. J., Van Dijk, J. A., and De Haan, J. (2017). The relation between 21st-century skills and digital skills: A systematic literature review. *Computers in Human Behavior*, *72*, 577-588.

Wilson, R. (2013). Skills anticipation—The future of work and education. *International Journal of Educational Research*, *61*, 101-110.

Zirpoli, F., and Moretti, A. (2019). Osservatorio sulla componentistica automotive italiana 2019. ANFIA, Torino.

Chapter 4

Developing human capital in the Emilian Motorvalley: engineering the future of the metalworking industry

Giuseppe Caruso and Fabrizio Patriarca

1. Introduction

New technologies are changing the nature of work, having an impact on the production process and increasing the demand for a highly skilled labour force. These effects are noticeable in numerous industries, especially in fields such as metalworking. Since the last century, economic and social literature has analysed the long-term effects of technological innovation on workers. In 1934, Schumpeter analysed the careers of workers exposed to the most technological change.

In modern economies, FDI, technological shocks and human capital are generally considered to be the three main drivers of growth and development (Romer, 1986; Dunning, 1993; Barro and Salazar-Martin, 1995). Human capital refers to the skills possessed by a worker. These skills can be acquired through education (generic human capital) or through work experience (specific human capital) (Teixeria and Lehmann, 2014). Kuznets (1966) highlights the significance of accumulating human capital to maintain economic growth and technological progress in global markets. This highlights the close relationship between two of the three drivers: human capital accumulation and technological development. Human capital accumulation determines a country's capacity to absorb technological innovation and grow. According to growth theory, technological development is distributionally inefficient. The diffusion of technology in the economy depends on local firms developing human capital; indeed, technology cannot be freely transferred between firms, given the substantial investment in R&D and the highly educated human capital needed to ensure proper integration. As a result, there are differences in technological capabilities between countries (Lall, 1992; Pack and Saggi, 1997).

Economic growth models have increasingly emphasised the importance of human capital. Lucas (1988) argues that human capital, like physical capital, is an input in the economy's production function. However, it is formed by workers through specific actions, such as education and training in the workplace. Romer (1986, 1990) defined human capital as the main driver of technological change resulting from firms investing in R&D. Acemoglu's (1996, 1998) work emphasizes the close relationship between technological change, FDI, and the formation of a competitive workforce. David (2013) highlights the importance of investing in human capital to improve productivity in the economy.

Focusing on generic human capital, this paper analyses the main skills acquired by engineering graduates hired in the Emilia-Romagna region. Specifically, it examines the mathematical, scientific, mechanical, digital and foreign language skills of engineering graduates from the University of Modena and Reggio Emilia between 2013 and 2020 hired within one year of graduation in metalworking companies in the region. The aim of the study is to identify the most in-demand skills in the metalworking sector. The study identified five macro competences based on the graduates' exam performance during their studies. On the basis of the exam scores, the skills are categorised into low, medium and high levels. This classification allows to determine the level of competence in each area for each individual graduate.

2. Data

This paper analyses data on engineering graduates from the Universities of Modena and Reggio Emilia between 2013 and 2020. The data was obtained from the Almalaurea survey on graduate employment one year after graduation and cross-referenced with administrative and sample data at the student level. The research aims to identify the most sought-after skills among engineering graduates. The Almalaurea survey provides data on the employment status of graduates and the relevance of their degree to jobs and industries. The analysis focuses on information from the one-year Almalaurea survey, supplemented by details from Unimoredata, which includes administrative information such as exam results and academic career information. The dataset analysed includes the complete academic history of the graduates, as well as their employment status one year after graduation.

The study analyses a sample of 2,146 engineering graduates between 2013 and 2020, consisting of 1,724 men and 422 women, who reported being employed one year after graduation. Table 1 shows the graduates' employment sector distribution.

Industrial activity	Frequency	Percent(%)	Cumulative Percent (%)
Metalworking	661	30.8	30.8
Other manufacturing industry	259	12.1	42.9
IT	236	11	53.9
Construction	168	7.8	61.7
Consulting	165	7.7	69.4

Trade	161	7.5	76.9
Other business services	153	7.1	84
Education	113	5.3	89.3
Chemistry	68	3.2	92.5
Transport	43	2	94.5
PA	43	2	96.5
Credit	23	1.1	97.6
Agriculture	13	0.6	98.2
Healthcare	9	0.4	98.6
Does not answer	31	1.4	100
Total	2,146	100	

Tab 1. Distribution of graduates by industrial activity

One year after graduation, 30.8% of graduates were employed in the Metalworking, 12.1% in other manufacturing industry and 11% in IT. Construction was also significant, with 7.8% of graduates having reported working in this sector one year after graduating. However, Consulting also plays an important role in employing graduates, accounting for 7.7%. Other important sectors are Trade (7.5%) and Education (5.3%).

The focus of this paper is the development of skill areas that students acquire through examinations and courses taken at university. Tertiary education aims to develop specific areas of competence. In order to define these areas, the competences of engineering students have been assessed through examination results. The exams are divided into five groups: mathematical, scientific, mechanical, digital and foreign language skills. As per previous research (Rosenberg and Nelson, 1994; Meyer and Schmoch, 1998; Umachandran et al., 2019; Kipper et al., 2021), the five defined areas represent essential skills for engineers in the job market. Student performance in examinations is used to indicate the student's ability in a specific area. Skills variables were created by calculating the average grade obtained by the student in the examinations belonging to that category. This grade was weighted by the value of the discipline within the degree programme. Each area of competence was then divided into three quantiles, allowing for the distinction between students with low, medium and high ability in that area. In particular, mathematical skills are assessed through examinations in disciplines directly related to algebra and mathematics. These include both applied and theoretical courses. Mechanical skills are evaluated through courses such as 'automotive engineering' and 'automotive mechanics'. Additionally, courses in Physics, Biology and Chemistry are essential for developing scientific skills, which are fundamental in the curricula of engineering students.

Language skills were assessed through English, Spanish and German language tests, while digital skills were evaluated through IT examinations.

Table 2 shows the five skill areas analysed. It also shows the average, minimum and maximum scores achieved by the students in the sample. The mean score for each category is calculated by averaging the scores obtained by the student in the exams belonging to that area. As previously stated, the scores are weighted based on the exam's relevance in the degree programme. In the Italian university system, the minimum passing score for an exam is 18 and the maximum is 30. The high standard deviation for skills such as digital and linguistic is particularly noteworthy.

Skill	Observations	Mean	Std. Dev.	Min	Max
Math skill	2.146	24,5	3	18	30
Scientific skill	2.146	24,6	2,5	18	30
Mechanical skill	2.146	25,1	2,9	18	30
Digital skill	2.146	25,3	4,1	18	30
Linguistic skill	2.146	25,5	3,5	18	30

Tab 2. Mean, standard deviation, min and max by skills

Table 3 displays the correlation between various areas of skills. Specifically, there is a strong correlation between a student's mathematical and scientific skills, as well as between mechanical and mathematical skills. No correlation exists between language and science skills, or between language and mechanical skills.

Skill	Math skill	Scientific skill	Mechanical skill	Digital skill	Linguistic skill
Math skill	1.000	0.4565	0.3689	0.2265	0.2228
Scientific skill	0.4565	1.000	0.3538	0.2188	0.0208
Mechanical skill	0.3689	0.3538	1.000	0.1601	0.0485
Digital skill	0.2265	0.2188	0.1601	1.000	0.1444
Linguistic skill	0.2228	0.0208	0.0485	0.1444	1.000

Tab 3. Correlation matrix by skills

Table 4 shows the distribution of the five competences. The low category represents the percentage of graduates with low skills, the medium category refers to graduates with average performance and the high category refers to graduates with high skills.

Skill	Low	Medium	High
Math skill	36,9	33,4	29,7
Scientific skill	35,3	37,2	27,5
Mechanical skill	38,1	30,2	31,7
Digital skill	40,5	31,5	28
Linguistic skill	54,1	30	15,9

Tab 4. Distribution of graduates by skills

The table shows that the most common skill among engineering graduates in the sample is mechanical knowledge. 31.7% of graduates have a high level of competence in this field.

However, only 15.9% of graduates in the sample have high foreign language skills, while 54.1% of engineers have very low language skills. In addition, 28% of graduates have high digital skills and 29.7% have high mathematical skills. Finally, 27.5% of the engineers in the sample have strong scientific skills, including knowledge of chemistry and physics that is of great relevance to many industries.

3. Tertiary education: knowledge and competences for industry

This section examines the correlation between industries and the five skill areas. The aim is to highlight the percentage of jobs that require high levels of mathematical, scientific, mechanical, digital and linguistic skills in different industries.

Figure 1 displays the distribution of students based on their mathematical skills. Mathematical literacy in this context refers to skills in mathematical analysis and logical thinking.

The variable has a score of 1 being low, 2 being medium and 3 being high. Education has the highest proportion of graduates with high mathematical literacy at 40.7%, followed by other manufacturing industry at 32.9% and metalworking at 32.1%. The lowest proportions of graduates with high mathematical literacy are in construction (22.4%) and IT (26.8%). The results are different when analysing the ability to understand and study scientific disciplines such as chemistry and physics.

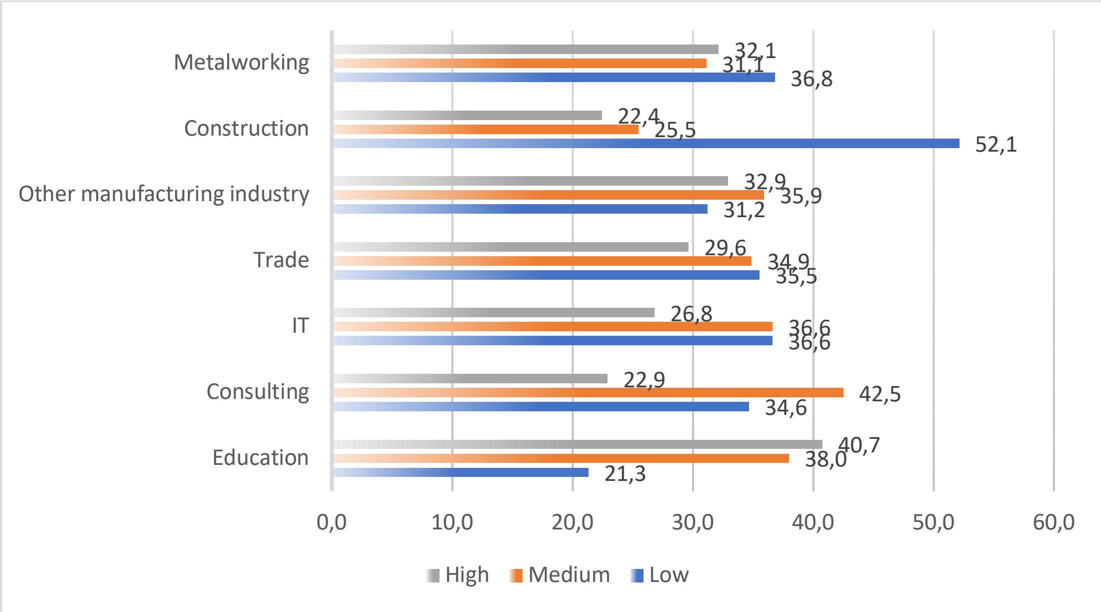


Fig 1. Maths skills of engineering graduates employed one year after graduating

Figure 2 analyses the percentage of graduates with high scientific literacy in different industries. The metalworking sector has 26.1% of graduates with high scientific literacy, while other sectors such as education (30%), consulting (29.5%) and other manufacturing industry (27.9%) have a higher proportion of graduates with high scientific literacy. In addition, 27% of engineering graduates employed in construction have a high level of scientific literacy.

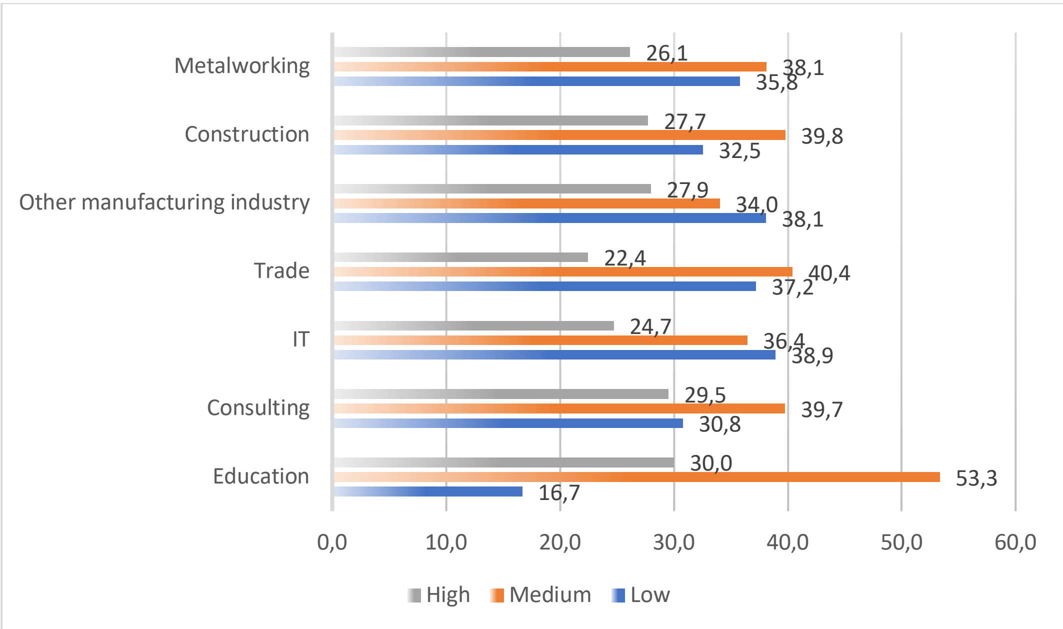


Fig 2. Scientific skills of engineering graduates employed one year after graduating

Mathematical and scientific skills are often closely related to technical skills, such as understanding general mechanics and solving related problems. Understanding of mechanical skills is crucial to graduate training and future employment in industries such as metalworking.

Figure 3 provides an analysis of the mechanical skills of engineering graduates employed in different industries. The data show that mechanical skills are required to work in metalworking. Specifically, 29.4% of engineering employed in metalworking acquired high mechanical skills during their studies. Mechanical knowledge is crucial in several sectors, including construction (27.8%), manufacturing (26%), trade (29.1%) and IT (40.7%). Graduating students with good levels of mechanical knowledge have the necessary skills to perform well in these sectors. Finally, more than half of the students with advanced mechanical knowledge choose a career path within the education sector (51.5%).

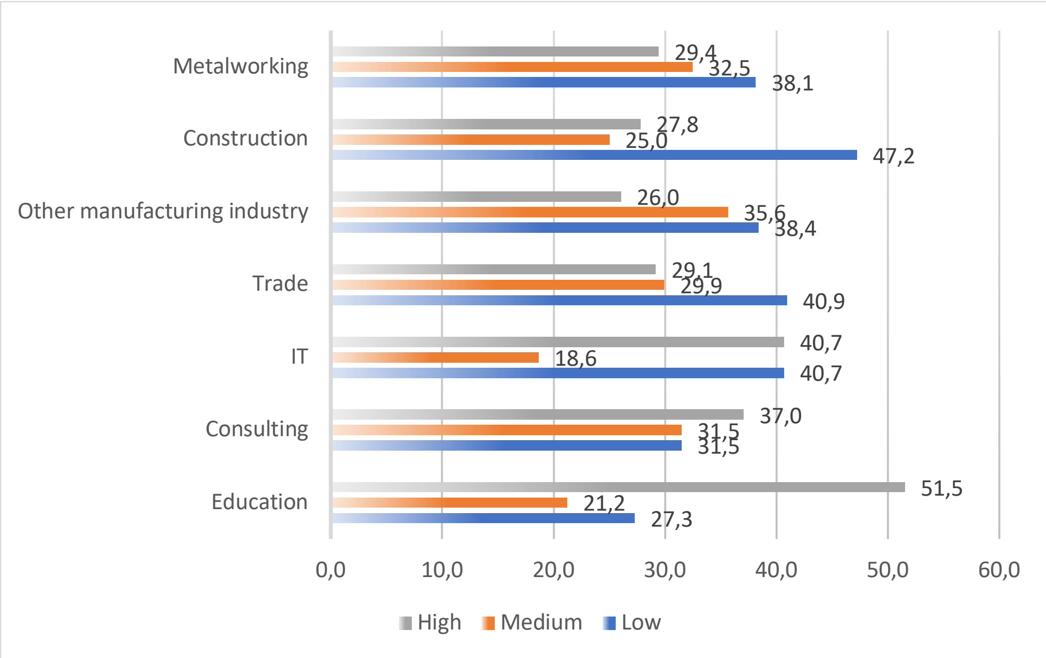


Fig 3. Mechanics-related skills of engineering graduates employed one year after graduating

Given the importance of new technologies and the interest of large companies in providing digital skills through higher education, the following analysis examines the proportion of graduates with high digital skills employed in different industries. Figure 4 illustrates the digital skills of engineering employed in different sectors.

The data show more graduates employed in construction and trade with high digital skills than in manufacturing. In addition, other manufacturing industries also have a high proportion of employees with high digital skills. Conversely, the proportion of graduates with high digital skills is relatively low in consulting at only 14.3%. In the IT enterprise sector, 40% of employed graduates possess advanced digital skills.

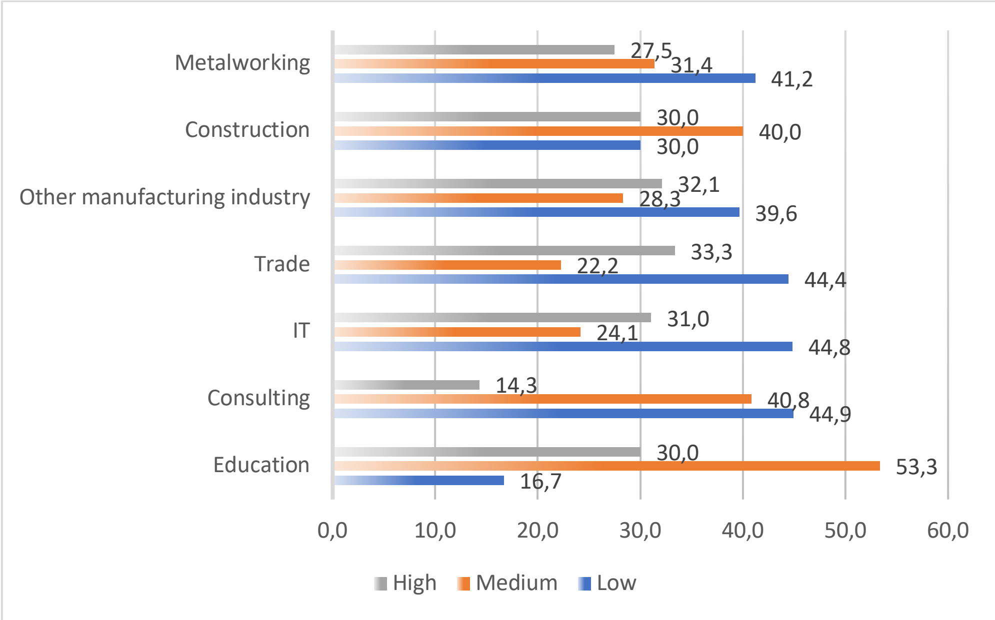


Fig 4. Digital skills of engineering graduates employed one year after graduating

Finally, Figure 5 highlights the link between industries and graduates' language skills. In the current globalising world, language skills are particularly important in many firms. For example, in the metalworking sector, only 19.9% of engineering have high language skills, and the percentage is even lower in other manufacturing industry, where it falls to 13.9%. In the trade sector, the percentage of graduates with high language skills drops to 11.8%, as does the consulting sector (3.9%). However, language skills are high in the IT sector (40%).

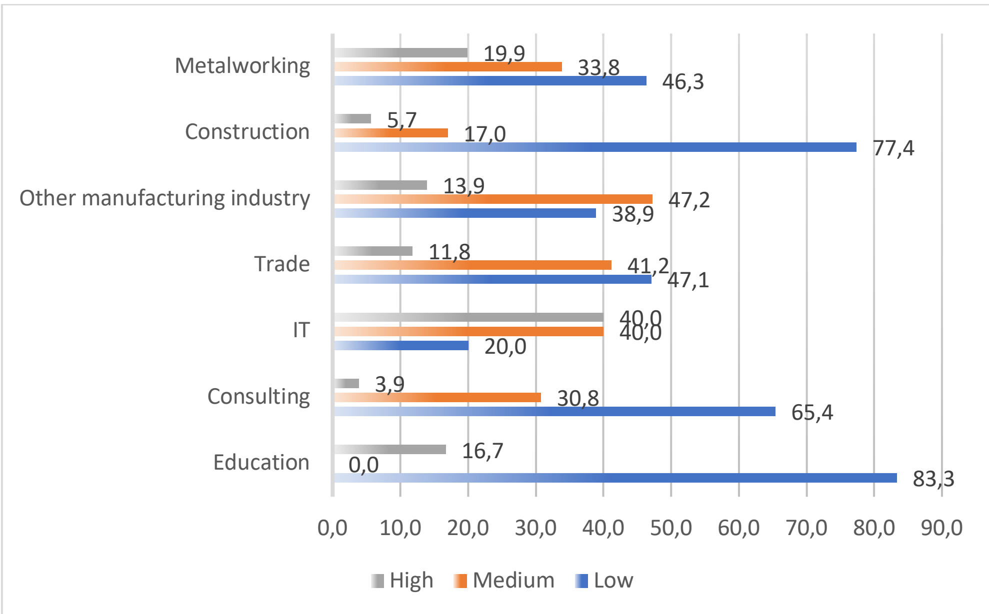


Fig 5. Linguistic skills of engineering graduates employed one year after graduating

These five skills have varying levels of importance across different industries. Strong mathematical skills may be prioritised in some industries, while technical skills may be prioritised in others. The following section provides a detailed analysis of the importance of these skills in the manufacturing sector, with the aim of determining the impact of tertiary education on the acquisition of skills by enterprises operating in this sector.

4. Skills in metalworking

Our analysis focuses on the metalworking sector in Emilia-Romagna. This sector has undergone significant structural and technological changes in recent decades. This has led to a transformation of the sector. As new technologies and production methods become more widespread, global companies are acquiring skills within the sector. The literature suggests that skills can be acquired through workplace training or higher education. The aim of this paper is to define and identify the higher education skills that are most in demand and most acquired in the metalworking sector of the Emilia-Romagna region. It focuses on the employment situation of engineering graduates from the University of Modena between 2013 and 2020. The analysis of the working conditions of graduating students upon entering the job market is based on the five skill areas previously identified: mathematics, science, digital, language and mechanical skills. These skill areas were identified based on the curriculum followed by the students during their higher education.

In Figure 6 we analyse the percentage of highly qualified graduates in each of the skill areas.

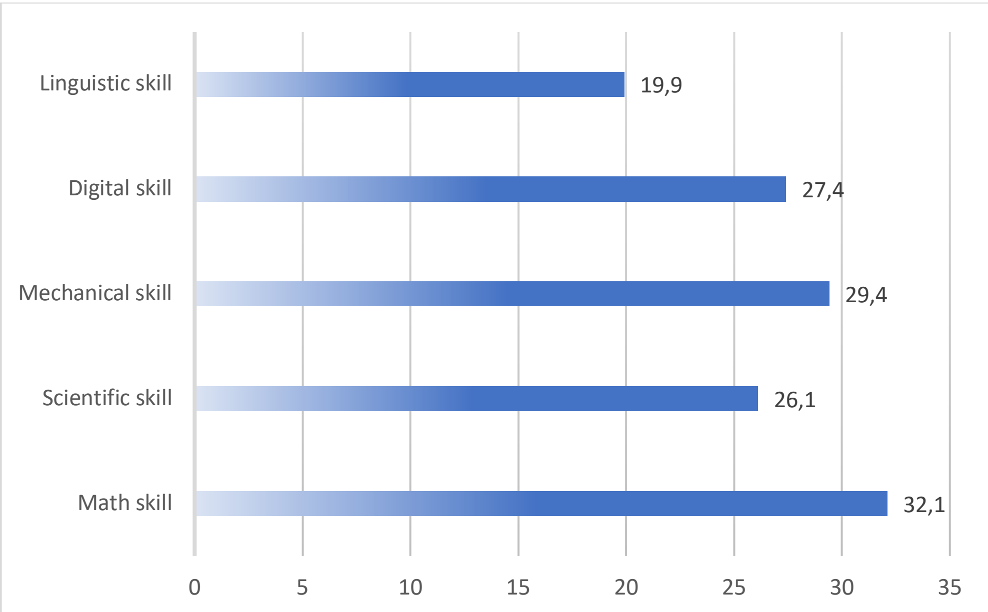


Fig 6. Skills of engineering graduates employed in Metalworking one year after graduating

In this way, we can identify the skills that appear to be the main focus of metalworking enterprises. The data show that 32.1% of employees in this sector have high mathematical skills, which are a necessary requirement for employment. On the other hand, only 19.9% of engineers recruited in the metalworking sector have high language skills. This suggests that language skills are less important and not a prerequisite for recruitment. Digital competence is an important skill in engineering too, with 27.4% of employed engineers being highly digital literate. Additionally, knowledge of mechanics concepts (29.4%) and scientific subjects such as physics and chemistry (26.1%) are also important.

Figure 7 analyses the share of engineers with high skills in the five key areas recruited by the industry between 2013 and 2020 to illustrate how the demand for skills has changed over time in response to the evolving needs and requirements of metalworking companies.

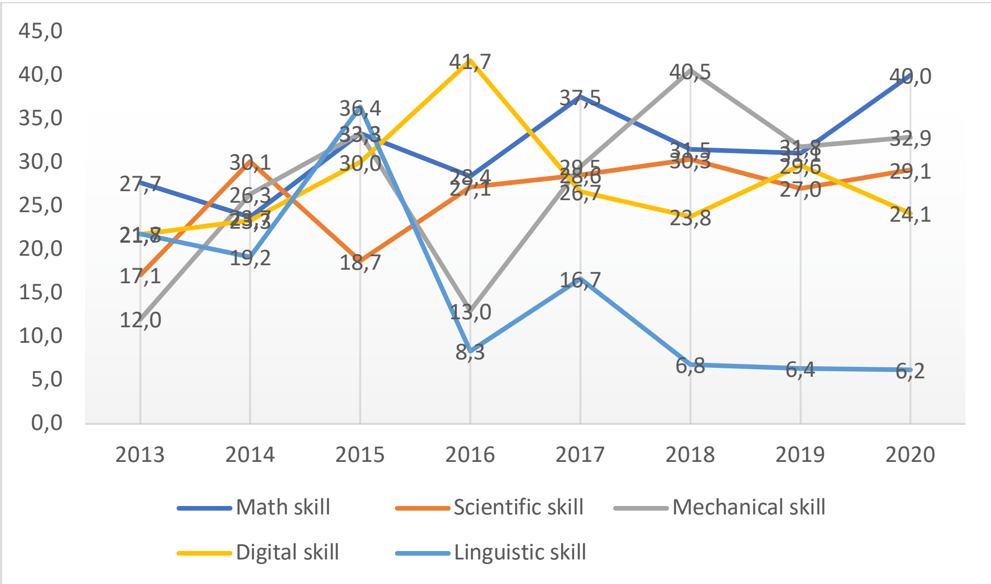


Fig 7. Skills of engineering graduates employed in Metalworking between 2013 and 2020

The trends vary considerably, highlighting the specificities of the sector. The decline in the importance of language skills is evident, with the number of graduates with high language skills falling from 21.8% in 2013 to 6.2% in 2020. There is also a sharp decline in the importance of digital skills, which peaked in 2016 at 41.7% of high-skilled hires. On the one hand, the share of engineers with high mathematical skills has increased significantly from 27.7% in 2013 to 40% in 2020, showing a steady upward trend. On the other hand, the share of engineers with high scientific skills has also increased, rising from 17.1% in 2013 to 29.1% in 2020, and continuing to rise in recent years.

Having identified the proportion of highly skilled engineering recruits between 2013 and 2020, we examined entry conditions in terms of salary and tenure. The analysis aims to highlight any correlation between the skills required and recruited by enterprises in the sector and the working conditions offered to new recruits. Table 5 shows the average wage offered to employees recruited in the manufacturing sector, categorised by skill level.

The data show that workers with high mathematical skills earn an average wage of €1,510, which is 3.1% higher than the €1,464 earned by workers with low mathematical skills. In the same way, workers with high digital skills are earning as much as €1630, whereas workers with low digital skills are earning just €1426. Furthermore, although scientific skills do not seem to have a significant impact on wages, having sufficient knowledge of mechanical subjects can result in a 4% higher salary compared to those with the least mechanical skills. Finally, language skills do not seem to affect the salaries of engineers.

Skill	Low	Medium	High
Math skill	1.464	1.482	1.510
Scientific skill	1.454	1.497	1.479
Mechanical skill	1.456	1.515	1.516
Digital skill	1.426	1.481	1.630
Linguistic skill	1.437	1.467	1.433

Tab 5. Wages of engineering graduates employed in Metalworking by skill level

However, the analysis of the effect of skills on the average time to employment in the industry yields similar results. Table 6 shows the average time to employment in manufacturing for an engineering graduate based on their skills in the five fields. Higher levels of maths and science literacy have a significant impact on reducing the job search time from 3.1 months to 2.4 months and 3 months to 2.2 months respectively. However, the largest reduction is observed for high digital literacy, reducing the time to 1.9 months for employment in metalworking. It is worth noting that there is no clear correlation between the time taken and high levels of language proficiency.

Skill	Low	Medium	High
Math skill	3,1 months	2,2 months	2,4 months
Scientific skill	3 months	2,5 months	2,2 months
Mechanical skill	3,4 months	2,2 months	2,5 months
Digital skill	3,8 months	2,7 months	1,9 months
Linguistic skill	2,4 months	2,5 months	2,4 months

Tab 6. Time to employment in Metalworking of engineering graduates by skill level

Figure 8 shows the percentage of highly qualified employees with a permanent contract on entry in five skills areas. Engineering graduates with high digital or science skills have a 39.3% chance of obtaining a permanent contract within the first year of employment. Similarly, graduates with high mathematical skills have a 39.1% chance. However, the percentage drops for graduates with good mechanical or language skills.

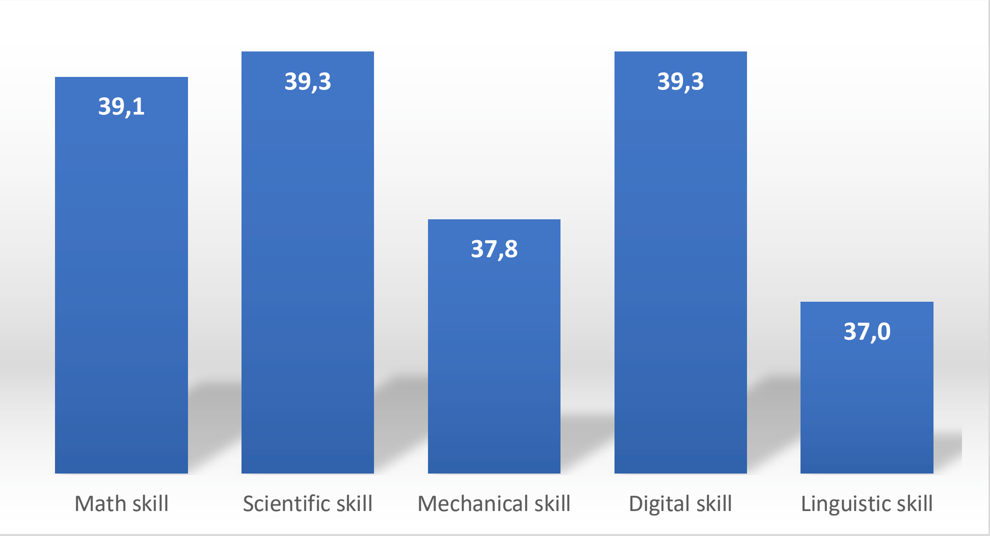


Fig 8. Percentage of high-capacity engineers hired on a permanent contract

The following figures analyse the percentage of employment in the sector by province in Emilia-Romagna, highlighting the importance of specialisation for Motorvalley enterprises. Figure 9 shows the percentage of engineering graduates employed in the metalworking sector in the different areas of Emilia-Romagna. The darker blue shading indicates a higher percentage. As expected, employment rates are high in Modena and Reggio Emilia, while Bologna and Parma also have significant numbers of engineering graduates. In contrast, Ravenna and Ferrara have a lower percentage of engineering graduates in employment.

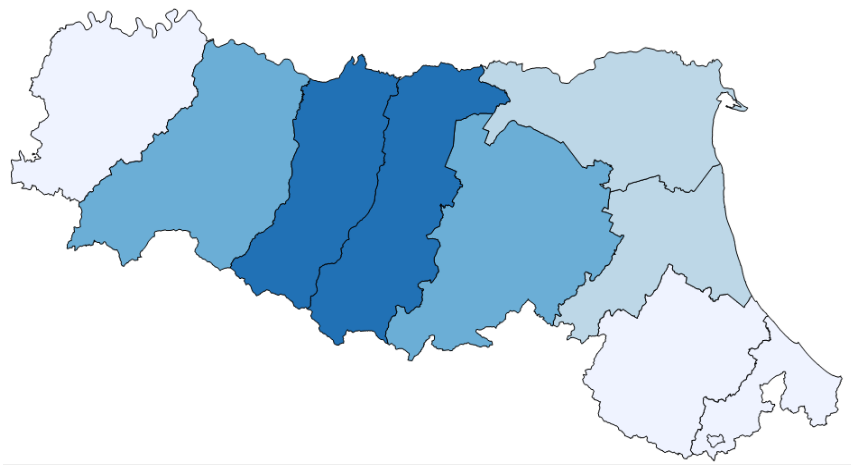
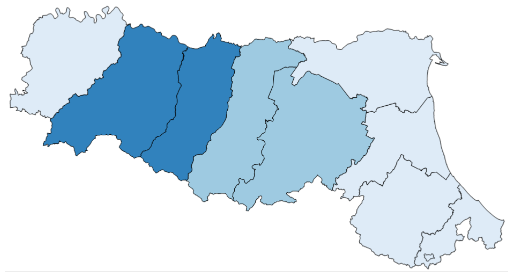
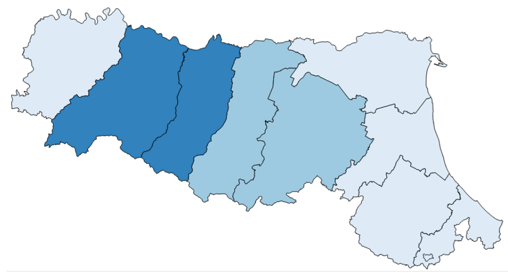
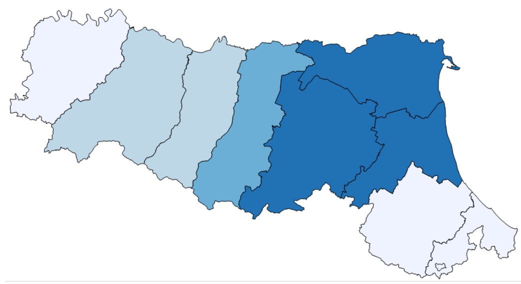
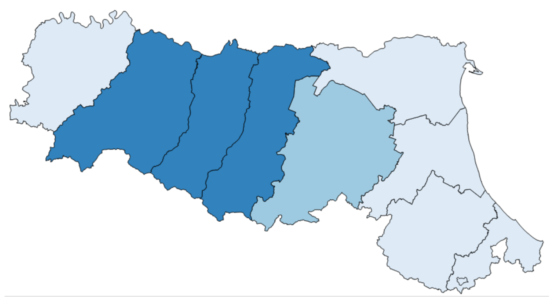


Fig 9. Percentage of engineering graduates hired in Metalworking sector by province in Emilia Romagna

Finally, Figure 10 analyses the percentage of engineering graduates employed in metalworking in Emilia-Romagna by qualification and province. This highlights the skills that are most in demand among engineers in the different provinces. During the period under review, Reggio Emilia and Parma recruited engineers with strong mathematical and scientific skills. These skills are also highly valued by the metalworking sector in the provinces of Modena and

Bologna. Firms in Bologna, Ravenna, and Ferrara were most likely to recruit graduates with advanced mechanical skills, while the metalworking industry in Modena, Reggio Emilia, Parma and Piacenza was most likely to require engineers with advanced digital skills. Language competence is especially important in Bologna, Modena and Reggio Emilia, perhaps because their firms have an international orientation.

High math skills	
High scientific skills	
High mechanical skills	
High digital skills	

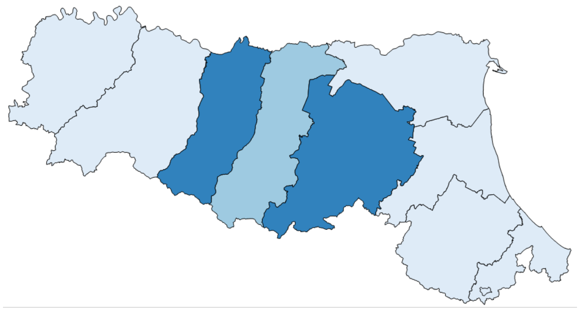
High languages skills	

Fig 10. Percentage of engineering graduates hired in Metalworking sector by province and high skills

In Emilia-Romagna, mathematics skills are essential for working in the metalworking industry. It is worth noting that there are significant territorial differences that highlight the diverse needs of the industrial sectors in the various provinces. Furthermore, the results are significantly influenced by time periods. Over time, the need for digital and language skills decreases, while the importance of mathematical and technical skills increases significantly.

5. Skills assessment in the metalworking industry

This section analyses the impact of qualifications on the likelihood of being employed in the metalworking industry within the first year for engineering graduates (see Table 7) and on the likelihood of earning a wage above 1400 euro (see Table 8). We can define the impact of different skills on the dependent variable to define the main determinants of employment in metalworking industry. The model is specified as follows.

$$Pr\ (Y = 1) = \Phi\ (\alpha + \beta X + \delta Z + \varepsilon) \quad (1)$$

The variable Y is binary, taking the value 1 if the graduate is hired in the metalworking industry and 0 otherwise. Therefore, the left-hand side represents the probability of being hired in the sector. The function Φ specifies the Probit model on the right-hand side. The vector X contains the set of dummy control variables such as gender, nationality (Italian or non-Italian), geographical origin, type of high school, final grade, time to graduation and information about the academic curriculum. Z is the vector containing the variables of interest, representing the five skill areas: mathematical, scientific, mechanical, digital and linguistic skills. The five skills variables are categorical and can take the values 1 for low, 2 for medium and 3 for high. According to the econometric analysis, students with strong mathematical skills are more likely to find employment in the metalworking industry. Engineers with a solid foundation in physics and chemistry often opt to work in other industries. Model 5 also indicates that individuals with high digital skills are less likely to be employed in this sector, even when controlling for science and language skills. The descriptive analysis supports this finding, indicating a significant decline in the employment of metalworking graduates with advanced digital skills in recent years.

	Model 1	Model 2	Model 3	Model 4	Model 5
High math skill	0.0557*	0.0691*		0.171*	
	(0.0337)	(0.0389)		(0.0921)	
High scientific skill	-0.0307			-0.161*	-0.245
	(0.0343)			(0.0746)	(0.251)
High mechanical skill		0.0141	0.153		
		(0.0379)	(0.192)		
High digital skill					-0.354*
					(0.146)
High linguistic skill			-0.0902	-0.00144	-0.227
			(0.183)	(0.0956)	(0.168)

Tab 7. Probability of employment in the Metalworking sector by skill

In the same way, Table 8 examines the probability of being paid more than the average (1,400 euro) in the first year of employment in the metalworking industry. The model follows the same definition, except that it uses a different dependent variable, Y. Y takes the value of 1 if the graduate earns more than 1,400 euro in the first year of employment, and 0 otherwise. Again, it is clear that mathematical competence is essential for metalworking engineers. The likelihood of a metalworking engineer earning more than €1,400 increases with high mathematical competence (models 1, 2 and 4). Moreover, high scientific skills are associated with less likelihood of high salary at identical mathematic and verbal skills (Model 4). No significant effect on wages was observed for other skills.

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
High math skill	0.150***	0.101***		0.194*		
	(0.0271)	(0.0305)		(0.0774)		
High scientific skill	-0.0891**			-0.218**	-0.298	
	(0.0306)			(0.0775)	(0.177)	
High mechanical skill		-0.0190	-0.125		-0.152	
		(0.0303)	(0.181)		(0.176)	
High digital skill						0.0213
						(0.0303)
High linguistic skill			0.159	-0.0269	0.208	
			(0.134)	(0.102)	(0.123)	

Tab 8. Probability of obtaining a salary higher than €1.400 in the Metalworking sector by skill

6. Final remarks

The aim of this research is to examine the generic accumulation of human capital through higher education. It aims to show how tertiary education can contribute to the formation of useful human capital. As highlighted in the literature (Teixeria and Lehmann, 2014), the skills developed by workers during their employment are related to skill sets derived from education. The analysis focuses in particular on engineering graduates and the metalworking sector in Emilia-Romagna, which is currently undergoing significant structural changes due to the adoption of new technologies. Consequently, the acquisition of key skills is essential for the transformation of production activity.

The analysis focuses on the most desirable skills for companies in the region acquired by graduates of the University of Modena and Reggio Emilia between 2013 and 2020. Graduating students were classified into five skill groups: mathematical, scientific, mechanical, digital and linguistic skills. The study aimed to identify the characteristics of these graduating students at the time of employment. The results show that mathematical skills are crucial for the metalworking industry. The data show that there is a significant correlation between mathematical skills and employment in the metalworking industry, as well as the earnings of engineering graduates in their first year of employment. The impact of language skills and digital literacy skills is less pronounced. However, the trend over time suggests that these skills are becoming more common in the industry and are no longer considered to be essential. There is also a negative correlation between advanced scientific skills, such as knowledge of chemistry and physics, and working in metalworking. It appears that engineers with a high level of competence in these areas prefer work in other industries.

Other manufacturing sectors could be explored in further research. The current study provides insights into the skills that are most in demand and required by metalworking companies, allowing a comprehensive comparison of skills in demand across the economy. This has valuable implications for industrial policy in relation to the skills required for work in the metalworking sector.

References

Acemoglu, D. (1996). A microfoundation for social increasing returns in human capital accumulation. *The Quarterly Journal of Economics, 111*(3), 779-804.

Acemoglu, D. (1998). Why do new technologies complement skills? Directed technical change and wage inequality. *The Quarterly Journal of Economics, 113*(4), 1055-1089.

Barro, R. and Sala-i-Martin, X. (1995). Economic growth. Cambridge, MA: McGraw-Hill.

David, P. A. (2000). Knowledge, capabilities and human capital formation in economic growth. *New Zealand Treasury Working Paper, 1*,13.

Dunning, J. (1993). Multinational enterprises and the global economy. Wokingham, UK: Addison-Wesley Publishing Company.

Kipper, L. M., Iepsen, S., Dal Forno, A. J., Frozza, R., Furstenau, L., Agnes, J., & Cossul, D. (2021). Scientific mapping to identify competencies required by industry 4.0. *Technology in Society, 64,* 101454.

Kuznets, S. (1966). Modern economic growth: rate, structure, spread. New Haven: Yale University Press.

Lall, S. (1992). Technological capabilities and industrialization. *World Development, 20* (2), 165-186.

Lucas Jr, R. E. (1988). On the mechanics of economic development. *Journal of Monetary Economics, 22*(1), 3-42.

Meyer-Krahmer, F., and Schmoch, U. (1998). Science-based technologies: university–industry interactions in four fields. *Research Policy, 27*(8), 835-851.

Pack, H. and Saggi, K. (1997). Inflows of foreign technology and indigenous development. *Review of Development Economics, 1*(1), 81-98.

Romer, P. (1986). Increasing returns and long-run growth. *Journal of Political Economy, 94* (5), 1002–1037.

Romer, P. M. (1990). Endogenous technological change. *Journal of Political Economy, 98*(5, Part 2), S71-S102.

Rosenberg, N., and Nelson, R. R. (1994). American universities and technical advance in industry. *Research Policy, 23*(3), 323-348.

Schumpeter, J. A. (1934). The theory of economic development: An inquiry into profits, capital, credit, interest and the business cycle. Cambridge, Mass.: Harvard University Press.

Teixeira, A. A. C. and Lehmann, A. T. T. (2014). Human capital intensity in technology-based firms located in Portugal: Does foreign ownership matter? *Research Policy, 43,* 737–748.

Umachandran, K., Corte, V. D., Amuthalakshmi, P., Ferdinand-James, D., Said, M. M. T., Sawicka, B., and Jurcic, I. (2019). Designing learning-skills towards Industry 4.0. *World Journal on Educational Technology: Current Issues, 11*(2), 12-23.

References

Acemoglu, D. (1996). A microfoundation for social increasing returns in human capital accumulation. *The Quarterly Journal of Economics, 111*(3), 779-804.

Acemoglu, D. (1998). Why do new technologies complement skills? Directed technical change and wage inequality. *The Quarterly Journal of Economics, 113*(4), 1055-1089.

Acemoglu, D., and Pischke, J. S. (1998). Why do firms train? Theory and evidence. *The Quarterly Journal of Economics*, *113*(1), 79-119.

Acemoglu, D., and Pischke, J. S. (1999). The structure of wages and investment in general training. *Journal of Political Economy*, *107*(3), 539-572.

Acemoglu, D., and Autor, D. (2011). Skills, tasks and technologies: Implications for employment and earnings. In *Handbook of Labor Economics, 4,* 1043-1171, Elsevier.

Alfonso-Hermelo, D., Langlais, P., and Bourg, L. (2019). Automatically learning a human-resource ontology from professional social-network data. In *Advances in Artificial Intelligence: 32nd Canadian Conference on Artificial Intelligence, Canadian AI 2019, Kingston, ON, Canada, May 28–31, 2019, 32,* 132-145, Springer International Publishing.

Amighini, A., and Gorgoni, S. (2014). The international reorganisation of auto production. The *World Economy, 37*(7), 923-952.

ANFIA (2023), Osservatorio sulla componentistica automotive italiana e sui servizi per la mobilità. ANFIA, Torino.

Arntz, M., Gregory, T., and Zierahn, U. (2017). Revisiting the risk of automation. *Economics Letters*, *159*, 157-160.

Attewell, P. (1992). Technology diffusion and organizational learning: The case of business computing. *Organization Science*, *3*(1), 1-19.

Autor, D., and Dorn, D. (2009). This job is "getting old": measuring changes in job opportunities using occupational age structure. *American Economic Review*, *99*(2), 45-51.

Baldwin, R., and Lopez-Gonzalez, J. (2015). Supply-chain trade: A portrait of global patterns and several testable hypotheses. *The World Economy, 38*(11), 1682-1721.

Barney, J. (1991). Special theory forum the resource-based model of the firm: origins, implications, and prospects. *Journal of Management*, *17*(1), 97-98.

Barro, R. and Sala-i-Martin, X. (1995). Economic growth. Cambridge, MA: McGraw-Hill.

Barrot, J. N., and Sauvagnat, J. (2016). Input specificity and the propagation of idiosyncratic shocks in production networks. *The Quarterly Journal of Economics, 131(*3), 1543-1592.

Bassanini, A., and Ernst, E. (2002). Labour market institutions, product market regulation, and innovation: cross-country evidence. *OECD Economics Department Working Papers, 316*, OECD.

Becker, B., and Gerhart, B. (1996). The impact of human resource management on organizational performance: Progress and prospects. *Academy of Management Journal*, *39*(4), 779-801.

Bentolila, S., and Bertola, G. (1990). Firing costs and labour demand: How bad is eurosclerosis?. *The Review of Economic Studies*, *57*(3), 381-402.

Bernhart, W. and Alexander, M. (2020). Computer on wheels: Disruption in automotive electronic and semiconductor. Roland Berger.

Bertola, G. (1990). Job security, employment and wages. *European Economic Review*,*34*(4), 851-879.

Berton, F., Richiardi, M., and Sacchi, S. (2012). The political economy of work security and flexibility. Italy in comparative perspective. Policy Press, Bristol.

Bierhanzl, E. (2005). Lessons from America. *Economic Affairs*, *25*(3), 17-23.

Bonadio, B., Huo, Z., Levchenko, A. A., and Pandalai-Nayar, N. (2021). Global supply chains in the pandemic. *Journal of International Economics, 133*, 103534.

Bonnal, L., Fougère, D., & Sérandon, A. (1997). Evaluating the impact of French employment policies on individual labour market histories. *The Review of Economic Studies, 64*(4), 683-713.

Calabrese, G. G., and Falavigna, G. (2022). Does Industry 4.0 improve productivity? Evidence from the Italian automotive supply chain. *International Journal of Automotive Technology and Management, 22*(4), 506-526.

Chryssolouris, G. (2013). Manufacturing systems: theory and practice. Springer Science and Business Media.

Cole, R. E., and Yakushiji, T. (1984). The American and Japanese auto industries in transition: report of the joint US–Japan automotive study. University of Michigan Press.

Contini, B., and Revelli, R. (1992). Imprese, occupazione e retribuzioni al microscopio: studi sull'economia italiana alla luce delle fonti statistiche INPS. Il Mulino, Bologna.

Contini, B., and Trivellato, U. (2005). Eppur si muove: Dinamiche e persistenze nel mercato del lavoro italiano. Il Mulino, Bologna.

Dallas, M. P., Ponte, S., and Sturgeon, T. J. (2019). Power in global value chains. *Review of International Political Economy, 26*(4), 666-694.

David, P. A. (2000). Knowledge, capabilities and human capital formation in economic growth. *New Zealand Treasury Working Paper, 1*,13.

Deloitte. (2020). Think tank. Automotive White Paper.

Deloitte. (2023). Automotive supplier study.

Deloitte. (2023). The future of automotive value chain. 2025 and beyond.

Devine, T. J., & Kiefer, N. M. (1991). Empirical labor economics: The search approach. Oxford University Press, USA.

Dicken, P. (2003). Global shift: Reshaping the global economic map in the 21st century. Sage.

Dunning, J. (1993). Multinational enterprises and the global economy. Wokingham, UK: Addison-Wesley Publishing Company.

Elmsekov, J., Martin, J. P., and Scarpetta, S. (1998). Key lessons for labour market reforms: evidence from OECD countries' experience. *Swedish Economic Policy Review*, *5*(2), 205-252.

Espitia, A., Mattoo, A., Rocha, N., Ruta, M., and Winkler, D. (2022). Pandemic trade: COVID-19, remote work and global value chains. *The World Economy, 45*(2), 561-589.

Fareri, S., and Solinas, G. (2021). Who rises and who drops? New technologies, workers, and skills. The case of a developed region, *Sinappsi – Connecting research and public policies*, anno XI, n. 2, 2021, 90-113

Fiorani G. and Simonazzi A. (2017), Two types of labor relations in practice: Ferrari and Lamborghini (mimeo).

Flori, E., Caruso, G., Pattarin, P. and Solinas, G. (2024). The global structure of the automotive industry: a network-based view. *International Journal of Automotive Technology and Management.* (in print, accepted, Jan. 24th, 2024)

Flori, E., Zhu, Y., Paterlini, S., Pattarin, F., and Villani, M. (2022). Spread of perturbations in supply chain networks: The effect of the bow-tie organization on the resilience of the global automotive system. In *Italian Workshop on Artificial Life and Evolutionary Computation,* 40-57. Cham: Springer Nature Switzerland.

Fonseca, D., Conde, M. Á., and García-Peñalvo, F. J. (2018). Improving the information society skills: Is knowledge accessible for all? *Universal Access in the Information Society*, *17*(2), 229-245.

Frey, C. B., and Osborne, M. A. (2017). The future of employment: How susceptible are jobs to computerisation?. *Technological Forecasting and Social Change*, *114*, 254-280.

Frigant, V., and Zumpe, M. (2017). Regionalisation or globalisation of automotive production networks? Lessons from import patterns of four European countries. *Growth and Change, 48*(4), 661-681.

Fulmer, I. S., and Ployhart, R. E. (2014). Our most important asset: A multidisciplinary/multilevel review of human capital valuation for research and practice. *Journal of Management*, *40*(1), 161-192.

Gaddi, M., and Garbellini, N. (2021). Automotive global value chains in Europe. *Institute for New Economic Thinking Working Paper Series, 160.*

Galati, F., and Bigliardi, B. (2019). Industry 4.0: Emerging themes and future research avenues using a text mining approach. *Computers in Industry*, *109*, 100-113.

Gereffi, G., and Korzeniewicz, M. (Eds.). (1993). Commodity chains and global capitalism. Bloomsbury Publishing USA.

Gereffi, G., and Sturgeon, T. (2004). Globalization, employment, and economic development: a briefing paper. Sloan *Workshop Series in Industry Studies 1*, 2. Rockport, Massachusetts.

Gereffi, G., and Fernandez-Stark, K. (2016). Global value chain analysis: a primer.

Giglioli, S., Giovannetti, G., Marvasi, E., and Vivoli, A. (2021). The resilience of global value chains during the Covid-19 pandemic: The case of Italy. *DISEI Working Paper,* 7/2021, Università degli Studi di Firenze.

Giovannetti, G., Mancini, M., Marvasi, E., and Vannelli, G. (2020). Il ruolo delle catene globali del valore nella pandemia: effetti sulle imprese italiane. *Rivista di Politica Economica, 2*, 77-99.

Goldin, C., and Katz, L. F. (1998). The origins of technology-skill complementarity. *The Quarterly Journal of Economics*, *113*(3), 693-732.

Gorecky, D., Schmitt, M., Loskyll, M., and Zühlke, D. (2014). Human-machine-interaction in the industry 4.0 era. In *2014 12th IEEE International Conference on Industrial Informatics,* 289-294.

Gorgoni, S., Amighini, A., and Smith, M. (2018). Automotive international trade networks: A comparative analysis over the last two decades. *Network Science, 6*(4), 571-606.

Grillitsch, M., Asheim, B., and Trippl, M. (2018). Unrelated knowledge combinations: The unexplored potential for regional industrial path development. *Cambridge Journal of Regions, Economy and Society*, *11*(2), 257-274.

Grubb, D., and Wells, W. (1993). Employment regulation and patterns of work in EC countries. *OECD Economic studies*, 7-7.

Heckman, J. J., and Pagés, C. (2000). The cost of job security regulation: Evidence from Latin American labor markets.

Hufbauer, G. C., and Jung, E. (2021). Economic sanctions in the twenty-first century. *Research Handbook on Economic Sanctions*, 26-43.

Iapadre, P. L., and Tajoli, L. (2014). Emerging countries and trade regionalization. A network analysis. *Journal of Policy Modeling, 36*, S89-S110.

Inoue, H., and Todo, Y. (2020). The propagation of economic impacts through supply chains: The case of a mega-city lockdown to prevent the spread of COVID-19. *PloS one, 15*(9), e0239251.

ISTAT (2023). Rapporto annuale 2023. La situazione del Paese. Roma.

Jacobs, A. J. (2023). The Korean auto industry reaches maturity and internationalizes, 2005–2019. In The Korean Automotive Industry, Volume 2: Asian Crisis to Today, 1997–2020, 59-94. Cham: Springer International Publishing.

Kano, L., Tsang, E. W., and Yeung, H. W. C. (2020). Global value chains: A review of the multi-disciplinary literature. *Journal of International Business Studies*, *51*, 577-622.

Kennan, J. (1985). The duration of contract strikes in US manufacturing. *Journal of Econometrics, 28*(1), 5-28.

Kipper, L. M., Iepsen, S., Dal Forno, A. J., Frozza, R., Furstenau, L., Agnes, J., & Cossul, D. (2021). Scientific mapping to identify competencies required by industry 4.0. *Technology in Society, 64,* 101454.

Klier, T. H., and Rubenstein, J. M. (2010). The changing geography of North American motor vehicle production. *Cambridge Journal of Regions, Economy and Society, 3*(3), 335-347.

Kuznets, S. (1966). Modern economic growth: rate, structure, spread. New Haven: Yale University Press.

Lado, A. A., and Wilson, M. C. (1994). Human resource systems and sustained competitive advantage: A competency-based perspective. *Academy of Management Review*, *19*(4), 699-727.

Lall, S. (1992). Technological capabilities and industrialization. *World Development, 20* (2), 165-186.

Lall, S., Albaladejo, M., and Zhang, J. (2004). Mapping fragmentation: Electronics and automobiles in East Asia and Latin America. *Oxford Development Studies, 32*(3), 407-432.

Lazear, E. P. (1990). Job security provisions and employment. *The Quarterly Journal of Economics*, *105*(3), 699-726.

Lee, J., and Gereffi, G. (2015). Global value chains, rising power firms and economic and social upgrading. *Critical Perspectives on International Business, 11*(3/4), 319-339.

Lee, N., and Cason, J. (1994). Automobile commodity chains in the NICs: a comparison of South Korea, Mexico, and Brazil. *Commodity Chains and Global Capitalism, 149*, 223.

Lefilleur, J. (2008). Geographic reorganization of the European automobile sector: What role for the Central and East European countries in an enlarged European Union? An empirical approach. *Eastern European Economics, 46*(5), 69-91

Lema, R., Rabellotti, R., and Gehl Sampath, P. (2018). Innovation trajectories in developing countries: Co-evolution of global value chains and innovation systems. *The European Journal of Development Research, 30*(3), 345-363.

Lucas Jr, R. E. (1988). On the mechanics of economic development. *Journal of Monetary Economics, 22*(1), 3-42.

Lung, Y. (2004). The changing geography of the European automobile system. *International Journal of Automotive Technology and Management, 4*(2-3), 137-165.

Lüthje, B., and Tian, M. (2015). China's automotive industry: structural impediments to socio-economic rebalancing. *International Journal of Automotive Technology and Management, 15*(3), 244-267.

Lüthje, B. (2021). Going digital, going green: Changing production networks in the automotive industry in China. *International Journal of Automotive Technology and Management, 21*(1-2), 121-136.

MacCrory, F., Westerman, G., Alhammadi, Y., and Brynjolfsson, E. (2014). Racing with and against the machine: Changes in occupational skill composition in an era of rapid technological advance.

MacDuffie, J. P. (2013). Modularity-as-property, modularization-as-process, and 'modularity'-as-frame: Lessons from product architecture initiatives in the global automotive industry. *Global Strategy Journal*, *3*(1), 8-40.

Mair, A., Florida, R., and Kenney, M. (1988). The new geography of automobile production: Japanese transplants in North America. *Economic Geography, 64*(4), 352-373.

Megyeri, E., Pelle, A., and Tabajdi, G. (2023). The realities of EU industrial policies analysed through automotive value chain dynamics. *Society and Economy, 45*(3), 250-269.

Mencarelli, E. and Mereu, M.G. (2021). Anticipazione dei fabbisogni professionali nel settore dell'automotive. INAPP, Roma.

Meyer-Krahmer, F., and Schmoch, U. (1998). Science-based technologies: university–industry interactions in four fields. *Research Policy, 27*(8), 835-851.

Moretti, A., and Zirpoli, F. (2020). Osservatorio sulla componentistica automotive italiana 2020. *Ricerche per l'Innovazione nell'Industria Automotive, 5.*

Moro, A., and Virgillito, M. E. (2022). Towards factory 4.0? Convergence and divergence of lean models in Italian automotive plants. *International Journal of Automotive Technology and Management, 22*(2), 245-271.

Muniz, S. T. G., and Belzowski, B. M. (2017). Platforms to enhance electric vehicles' competitiveness. *International Journal of Automotive Technology and Management, 17*(2), 151-168.

Noble, W. S. (2006). What is a support vector machine?. *Nature Biotechnology, 24*(12), 1565-1567.

Noelke, C. (2011). The consequences of employment protection legislation for the youth labour market. *Arbeitspapiere – Working Papers, 144.*

OECD. (1994). The OECD Jobs Study: Evidence and Explanations. Paris, OECD.

OECD. (2004). The OECD principles of corporate governance. *Contaduría y Administración, 216.*

Olejniczak, T., Miszczynski, M., and Itohisa, M. (2020). Between closure and Industry 4.0: strategies of Japanese automotive manufacturers in Central and Eastern Europe in reaction to labour market changes. *International Journal of Automotive Technology and Management, 20*(2), 196-214.

Pack, H. and Saggi, K. (1997). Inflows of foreign technology and indigenous development. *Review of Development Economics, 1*(1), 81-98.

Pavlínek, P. (2012). The internationalization of corporate R&D and the automotive industry R&D of East-Central Europe. *Economic Geography, 88*(3), 279-310.

Pavlínek, P. (2018). Global production networks, foreign direct investment, and supplier linkages in the integrated peripheries of the automotive industry. *Economic Geography, 94*(2), 141-165.

Pavlínek, P. (2020). Restructuring and internationalization of the European automotive industry. *Journal of Economic Geography, 20*(2), 509-541.

Pianta, M. (2018). Technology and employment: twelve stylised facts for the digital age. *The Indian Journal of Labour Economics*, *61*, 189-225.

Pryima, S., Dayong, Y., Anishenko, O., Petrushenko, Y., and Vorontsova, A. (2018). Lifelong learning progress monitoring as a tool for local development management. *Problems and Perspectives in Management*, *16*(3), 1-13.

Raj-Reichert, G. (2019). 22. The role of transnational first-tier suppliers in GVC governance. *Handbook on Global Value Chains, 354.*

Rarou, H. (2023). Global trends and spatiotemporal shifts in the automotive assembly footprint. *International Journal of Automotive Technology and Management, 23*(2-3), 121-143.

Rhys, D. G. (2004). The motor industry in an enlarged EU. *World Economy, 27*(6), 877-900.

Rogerson, R. (1987). An equilibrium model of industrial reallocation. *Journal of Political Economy*, *95*(4), 824-834.

Romer, P. (1986). Increasing returns and long-run growth. *Journal of Political Economy, 94* (5), 1002–1037.

Romer, P. M. (1990). Endogenous technological change. *Journal of Political Economy, 98*(5, Part 2), S71-S102.

Rosenberg, N., and Nelson, R. R. (1994). American universities and technical advance in industry. *Research Policy, 23*(3), 323-348.

Ruigrok, W., and Van Tulder, R. (2013). The logic of international restructuring: The management of dependencies in rival industrial complexes. Routledge.

Russo M., Pavone, P. and Cetrulo, A. (2018). Conflict and partecipation in bargaining. The Lamborghini Case. *Economia e Lavoro*, anno LIII, 53-74.

Russo, M. (2018). L'Industria automotive in Emilia-Romagna, Osservatorio sulla componentistica automotive italiana. ANFIA, Torino.

Russo, M., and Pentucci, P. P. (2019). La filiera della componentistica automotive in Emilia-Romagna. In *Osservatorio sulla componentistica automotive italiana 2019, 4*, 143-161. Ca'Foscari.

Schlie, E., and Yip, G. (2000). Regional follows global: Strategy mixes in the world automotive industry. *European Management Journal, 18*(4), 343-354.

Schumpeter, J. A. (1934). The theory of economic development: An inquiry into profits, capital, credit, interest and the business cycle. Cambridge, Mass.: Harvard University Press.

Simonazzi, A., Carreto Sanginés, J., and Russo, M. (2022). The world to come: key challenges for the automotive industry. *Economia e Lavoro, 57*(1), 7-23.

Smith, D. F., and Florida, R. (1994). Agglomeration and industrial location: An econometric analysis of Japan-affiliated manufacturing establishments in automotive-related industries. *Journal of Urban Economics, 36*, 23-41.

Sturgeon, T., and Florida, R. (2004). Globalization, deverticalization, and employment in the motor vehicle industry. In M. Kenney (Ed.), *Locating Global Advantage: Industry Dynamics in a Globalizing Economy*, 52-81. Stanford, Calif.: Stanford University Press.

Sturgeon, T., Van Biesebroeck, J., and Gereffi, G. (2008). Value chains, networks and clusters: Reframing the global automotive industry. *Journal of Economic Geography, 8*(3), 297-321.

Sturgeon, T., and Van Biesebroeck, J. (2010). Effects of the crisis on the automotive industry in developing countries: A global value chain perspective. *World Bank Policy Research Working Paper, 5330.*

Teixeira, A. A. C. and Lehmann, A. T. T. (2014). Human capital intensity in technology-based firms located in Portugal: Does foreign ownership matter? *Research Policy, 43,* 737–748.

Thun, E. (2006). Changing lanes in China: Foreign direct investment, local governments, and auto sector development. Cambridge University Press.

Timmer, M. P., Dietzenbacher, E., Los, B., Stehrer, R., and De Vries, G. J. (2015). An illustrated user guide to the world input-output database: the case of global automotive production. *Review of International Economics, 23*(3), 575-605.

Umachandran, K., Corte, V. D., Amuthalakshmi, P., Ferdinand-James, D., Said, M. M. T., Sawicka, B., and Jurcic, I. (2019). Designing learning-skills towards Industry 4.0. *World Journal on Educational Technology: Current Issues, 11*(2), 12-23.

Van Laar, E., Van Deursen, A. J., Van Dijk, J. A., and De Haan, J. (2017). The relation between 21st-century skills and digital skills: A systematic literature review. *Computers in Human Behavior*, *72*, 577-588.

Wang, X., Zhao, W., and Ruet, J. (2022). Specialized vertical integration: the value-chain strategy of EV lithium-ion battery firms in China. *International Journal of Automotive Technology and Management, 22*(2), 178-201.

Wilson, R. (2013). Skills anticipation—The future of work and education. *International Journal of Educational Research*, *61*, 101-110.

Womack, J. P., Jones, D. T., and Roos, D. (2017). The machine that changed the world. London&New York: Free Press (1st ed. 1990).

Zirpoli, F., and Moretti, A. (2019). Osservatorio sulla componentistica automotive italiana 2019. ANFIA, Torino.