COVID-19 and industrial resilience in the Global South. A case study on the auto parts sector in Mexico

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Abstract: The global COVID-19 pandemic has exposed the low level of resilience of supply chains and the fragility of employment in most economic sectors. This research, which is based on two independent online surveys, explores the level of readiness of automotive firms in Mexico to adopt I4.0 technologies, as well as the mitigation strategies adopted by such firms to overcome the economic effects of COVID-19. The results indicate a low level of readiness and understanding of I4.0 technologies in the automotive parts sector in Mexico and that most of the COVID-19 mitigation efforts have been focused on workforce management strategies, rather than on technological solutions.

Keywords: Industry 4.0; I4.0; automobile industry; supply chain; industrial resilience; COVID-19; Mexico.

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1 Introduction

The global COVID-19 pandemic not only affected the global health system and established economic systems, it also exposed the insufficient resilience of supply chains and the fragility of employment in most economic sectors. The impacts of the COVID-19 pandemic on the global economy have shown the low levels of readiness of manufacturing firms to react to major global disruptions and the critical relevance of digital technologies in manufacturing production.

This study addresses two independent trends that, in their intersection, influence the structure of employment worldwide. On the one hand, the adoption of Industry 4.0

(I4.0) technologies is a trajectory that started already in 2014, with a projected institutionalisation horizon by 2035 (Schwab, 2017). On the other hand, COVID-19 is a temporal and co-occurring factor affecting employment due to its related mobility and social distance restrictions. This study presents the intersection of these trends and questions if the emergence of COVID-19 has encouraged, or accelerated, the adoption of I4.0 technologies in Mexico's auto parts sector.

The rapid and global spread of COVID-19 has forced governments worldwide to impose (at different levels of intensity) a series of adaptive actions for isolation and the closure of non-essential businesses. The global discussion centred on the trade-off between hurting national economies or maintaining the stability of their health systems. The choice was made (with some infamous exceptions) to protect health systems by forcing lockdowns and releasing rescue plans to keep businesses from their economic losses. However, recent empirical analyses have shown that these policies have harmed the economy by reducing corporate performance (Shen et al., 2021; UNCTAD, 2020), having adverse effects on exchange rates (Iyke, 2020), influencing persistent shocks on oil prices (Gil-Alana and Monge, 2020), and other unforeseen economic effects.

Empirical studies from the supply chain resilience literature have found that one of the best strategies perceived by the automobile industry to mitigate the economic effects of COVID-19 has been the adoption of I4.0 technologies (Belhadi et al., 2021). Although the adoption of I4.0 technologies (i.e., digitalisation, robotisation, cloud computing, high performance computing, augmented reality, and artificial intelligence, among other things) has been changing the production, distribution, and managerial configuration of industries in the North for the last five to ten years, its adoption rate has not been as fast as predicted by the literature. The dependency of subsidiaries on original equipment manufacturers (OEMs) upgrading plans is extremely relevant to understand the processes through which I4.0 technologies are implemented and adopted in the Global South[1] (Gehl-Sampath and Vallejo, 2018; Szalavetz, 2019).

This study questions if Mexican auto parts firms have sought out or accelerated digital solutions to address the impacts of workforce restrictions brought about by COVID-19 and that might have long-lasting effects on accelerating technological change. The study uses two independent datasets to present an empirical analysis of the auto parts sector's technological readiness (just before the pandemic) and the strategies adopted to cope and survive the economic effects of the COVID-19 restrictive measures. The first survey addresses the level of knowledge and adoption of I4.0 technologies among auto parts firms in 2019. The second survey explores the mitigation and resilience strategies adopted by firms in the sector during the pandemic's first months. This research finds that although firms' immediate response to the local situation was employment management strategies, COVID-19 seems to have triggered an acceleration of firms' digitalisation plans to adopt I4.0 technologies. The study adds to the growing interest in the literature on supply chain resilience and the adoption of I4.0 technologies in manufacturing.

Section 2 sets out the framework of the study. It introduces the organisation of firms in the automotive industry, the industry's relationship with I4.0, and the effects of COVID-19 on the Mexican automotive sector. Section 3 outlines the research methodology. Section 4 presents the results of the empirical analysis. Section 5 contains a discussion of the main findings. Section 6 presents future research paradigms.

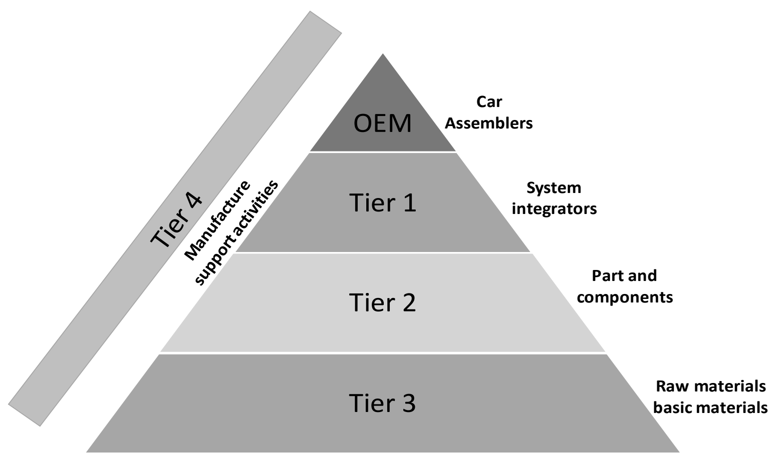
2 Framework of analysis

2.1 The automotive industry and its general structure

The automobile industry is characterised by a high level of globalisation and increasing investments by its leading assemblers in overseas manufacturing activities. It is a particularly relevant industry because of its wide set of interrelations with other industrial activities in the economy, which favours technological upgrading in the different auto parts firms and supporting industries.

The auto industry organises its suppliers in tiers according to the complexity of the products they produce (Vallejo, 2010). Traditionally, the industry resembles a pyramid, in which the auto assemblers are at the apex, followed by different auto parts firms at the different tiers. Following the assemblers are the auto parts first-tier suppliers, mainly large firms using their own production technologies in the manufacture of complex sets of automotive systems and subsystems (Lara et al., 2004). Next in line in the structure are the so-called second, and third-tier suppliers, which are the base of the pyramid. These suppliers, particularly the third-tier, are formed by domestic small and medium enterprises (SMEs). Most of the automotive sector employment is concentrated in the auto parts segment (which includes manufacturing support activities – MSAs).

Figure 1 Graphic representation of the Mexican automobile industry



Source: Elaborated by the authors

There are imported parts and components supplying inputs to all the tiers, including the terminal or assembling industry, alongside the pyramid. Fourth-tier suppliers are also present along the pyramid (see Figure 1). These are firms commonly known as the supporting industry, as they provide MSAs to other firms in the pyramid (Vallejo, 2010). These MSAs are not only part of the auto industry, as their core production specialisation is horizontal and includes plastics, metal-mechanics, technical and technological services. In Mexico, these firms are mostly spin-offs of auto parts Tier 1, where their owners and engineering teams have linkages with larger automotive firms allowing them to supply highly specialised services (Carrillo and Contreras, 2008; Contreras et al., 2012). They are generally domestic SMEs taking part in the implementation and design of I4.0 technologies by providing technical and technological services to automotive firms.

2.2 I4.0 and the automotive industry

I4.0, also known as smart manufacturing or industries of the future, is a term defined as an ongoing trend of automation, digitalisation, and data exchange in manufacturing technologies involving features like artificial intelligence, cloud computing, robotics and cyber-physical systems. It allows monitoring of the physical processes and making decisions to reshape industrial production by expanding production systems integration and reducing the costs and risks that arise during industrial producti (Kagermann et al., 2013).

Discussions on I4.0 technologies have given rise to academic and political discussions on the changes it may bring to the existing industrial environments and existing socio-economic relationships (Schwab, 2017; Zhong et al., 2017). As industrial sectors worldwide gradually adopt I4.0 technologies in the engineering and production area, more pressure is placed on the reorganisation, digitalisation, and reduction of the number of employees and product distributors (i.e., local counterparts), as well as to the adoption of intelligent platforms or e-commerce facilities.[2] Frey and Osborne (2017) predicted the substitution of about 70% of current occupations, and Schwab (2017) and Lee (2019) expect a major wave of 'relocations or back-reshoring' of manufacturing activities to the North.

In practice, these predicted scenarios have not fully occurred. Only 1 out of 4 subsidiaries have reshored back, and these have been mostly German firms (Dachs et al., 2019; Kinkel, 2018). Employment has also not been substituted or reconfigured to predicted levels (Autor et al., 2020; Fareri et al., 2020; Hirsch-Kreinsen, 2016; Sumer, 2018), and many other authors have found that I4.0 has generated new types of occupations (Chinoracky et al., 2020; Sumer, 2018). Most importantly, although factories in the Global North are gradually moving toward higher automation, digitalisation, and integration, there are not yet factories operating at the level of fully digital integration proposed by the I4.0 paradigm (Deng et al., 2021).

Without a doubt, the industrial trend is to move towards higher levels of digitalisation and automation (Autor et al., 2020). The automobile sector is one of the first industries adopting I4.0 technologies (ECLAC, 2018; Krzywdzinski, 2020). The participation of digital components in the automobile value has gradually increased, reshaping its value proposition and rapidly changing the global landscape of the sector (Llopis-Albert et al., 2021). CANIETI (2017) finds that about 40% of automobile value comes from electronic components and software, as more than 20% of machinery and equipment comes from control, robotics and automation elements. This participation of digitalisation in auto production and value is expected to keep increasing to 90% levels by 2035, according to Herbert Diess, Volkswagen CEO (March 13, 2019).[3]

ECLAC (2018, p.92) identifies four critical I4.0 technologies influencing the auto industry's future: connectivity, autonomous driving, artificial intelligence and electro-mobility. Hofstatter et al. (2020) also highlight the need for automotive manufacturers and their suppliers to invest in autonomous technologies, connectivity, electrification and shared mobility through strategic partnerships. UNCTAD (2020) highlights three key 4.0 technology trends (re)shaping industrial production:

robotics-enabled automation, enhanced supply chain digitalisation and additive manufacturing.

This type of investment by firms in I4.0 technologies is closely related to investment in intangibles. Brynjolfsson and Hitt (2000) and Brynjolfsson et al. (2019) stated that manufacturing firms investing in technologies such as ICT or artificial intelligence perceive a higher return in productivity from these investments when they also engage in complementary investments in intangible assets (i.e., human capital) than those firms investing less (or not) in intangibles.

This is particularly relevant for the Global South as I4.0 shifts the competitive advantage of manufacturing activities towards technology-based competitiveness and away from cheap labour (Chaabane, 2018; Vallejo, 2017). Since manufacturing production in the Global South is significantly linked to OEMs, particularly production for the export market (Gehl-Sampath and Vallejo, 2018), production activities coordination and planning is linked to OEMs' headquarter plans (Lampon et al., 2018; Rodriguez-de la Fuente and Lampon, 2020; Szalavetz, 2019).

2.3 COVID-19 and the auto industry

In the midst of this technological transformation process, in which firms were already struggling to remain integrated in the changing value chain, the automotive industry was hit by the COVID-19 pandemic. Worldwide, the COVID-19 pandemic has resulted in an unprecedented shock to the automotive industry (UNCTAD, 2020). The set of restrictive measures implemented in most countries to reduce the spread of COVID-19 has impacted on the supply chain of most industries, creating supply bottlenecks and a decline in consumer demand, leading to losses in globalised sectors such as the automobile sector (Guan et al., 2020; UNCTAD, 2020). This has led many firms to close or reduce operations; others have reported a drop in sales and many more have adjusted their workforce (Apedo-Amah et al., 2020).

During the first year of the pandemic, the automotive industry worldwide experienced a significant economic slowdown (UNCTAD, 2020). Hofstatter et al. (2020) estimate that about 20 automotive OEMs will experience a 16.6% drop in profits in 2021 compared to 2018.[4] The already slower demand for passenger vehicles in North America in late 2019 was exacerbated by the COVID-19 pandemic (Koenig, 2020). The first round of COVID-19 shutdowns lasted for about six weeks, during which time about 90% of manufacturing plants worldwide closed (Hausler et al., 2020). OEMs such as General Motors and Ford used credit lines to get through and restart production (Koenig, 2020). OEMs tightly managed cash flows and reviewed all non-essential expenses, i.e., freezing hiring, delaying capital expenditure plans (Accenture, 2020). Major automotive manufacturers halted production temporarily in most of their international facilities (UNCTAD, 2020). The pressure to reopen assembling operations worldwide resulted in the adoption of standard adaptive practices in the plants such as temperature checks, face masks, protective wear, Plexiglas, and weld barriers between workstations, as well as increased testing (Koenig, 2020). Other important measures included engineering solutions like the redesign of workstations, which required the complete redesign of some processes (Koenig, 2020).

Belhadi et al. (2021), in their study on supply chain resilience in automotive firms from the USA, Germany, Spain, France, Korea and Morocco, identify two immediate strategies to mitigate risks related to COVID-19:

1 develop localised supply sources

2 adopt advanced I4.0 technologies, with an emphasis in big data analytics.

On the first point, Hofstatter et al. (2020) highlight the sense of urgency over supply chain resilience by industry leaders. The first weeks of COVID-19 exposed the global supply chains' fragility and how the supply-induced shock has caused production interruptions at all supplying levels (Guan et al., 2020; Hofstatter et al., 2020). Hofstatter et al. (2020) report how manufacturers in Europe and the USA are considering local sourcing backups.

On the second point, studies have highlighted an increasing focus on digitised automation and the use of automated production systems, including robotics, in automotive firms after the first lockdown of the pandemic (Goel et al., 2020; Hofstatter et al., 2020). A focus on digital channels, asset deployment, zero-based budgeting, and building a resilient supply chain are windows of opportunity that automotive firms, particularly OEMs, are currently exploring to remain and emerge stronger after the COVID-19 crisis (Hofstatter et al., 2020). This research focuses on this second point by presenting the auto sector's situation in Mexico as a case study.

2.4 The auto industry in Mexico

The automotive industry in Mexico is particularly relevant as it exemplifies a worldwide industry located in a developing country and shaped by international organisational and technological standards. In 2017, Mexico was the seventh-largest manufacturer of automobiles and the fourth largest exporter of assembled vehicles (ECLAC, 2018; Guzman-Anaya, 2020). Its auto parts production is the sixth largest worldwide and it is the fifth largest auto parts exporter (ECLAC, 2018; Guzman-Anaya, 2020). In 2019, Mexico ranked sixth worldwide in the production of vehicles with about four million units (OICA, 2020).

In the last decades, the Mexican auto industry has evolved from low-cost platforms addressing vehicle assembly into an integrated production chain diversified in products and technological sophistication (Brincks et al., 2018; ECLAC, 2018). This transformation is due to a large amount of foreign direct investment (FDI) allocated to this industry across the country under the umbrella of the former North American Free Trade Agreement (NAFTA, since July 2020 called United States-Mexico-Canada Agreement – USMCA). About 73% of FDI in Mexico between 2005–2017 went to auto parts and components manufacturers (ECLAC, 2018). Although US OEMs make up about 31% of automotive firms in Mexico, Japanese and European OEMs are also significant, constituting about 35% and 25%, respectively, in 2017 (ECLAC, 2018). According to the Mexican Ministry of Economy (2020), the accumulated FDI for 2011–2020 was USD28.6 billion for OEMs and USD26 billion for auto parts.

Lampon et al. (2018) and Rodriguez-de la Fuente and Lampon (2020), in their comparison between the auto industry in Spain and Mexico, indicate a low level of decision-making power in the distribution and coordination of production activities of the automobile industry in Mexico, which highlights a dependency on decision-making by OEMs' foreign headquarters.

The COVID-19 pandemic put a halt to the dynamism and growth that Mexico's auto industry was having after the 2008 crisis. CEPAL (2020) informed that about 95% of Latin American firms were affected by the shutdowns related to COVID-19.

Movement restrictions policies also affected the inputs and workforce demand in the North American region (CEPAL, 2020). In Mexico, the COVID-19 restrictions shut down manufacturing operations from the end of March until mid-May 2020. This closing of activities led to a drop in national manufacturing production by about 43% for about two calendar months (Corona et al., 2020). During the lockdown period, automotive exports decreased by about 42% and domestic sales by about 32% (Corona et al., 2020). According to UNCTAD (2020), Mexico is one of the countries most affected by COVID-19 due to its high integration into the US automotive value chain, which exposed the country to significant supply chain disruptions.

By May 11, 2020, auto firms in the USA restarted operations (Koenig, 2020). The Mexican auto firms followed closely, opening their factories a few days later. After the March–May 2020 lockdown, the Mexican automotive sector was declared an essential activity, protecting it from future shutdowns. Nevertheless, as Carrillo and Rodriguez (2020) reported, about 10.3% of auto parts firms were never certain if they were an essential activity or not, due to lack of clarity in the official information. Ornelas (2021) highlights the excessive bureaucratic requirements of Mexican authorities for the reopening of OEMs and automotive suppliers after the March–May 2020 shutdown and the lack of governmental support, as well as the extra costs involved in implementing the mandatory safety measures.

The two most dynamic regions in Mexico for the automotive industry are the Northern region, which had an accumulated FDI of US24.7 billion from 2011–2020, and the Bajio region, which had about USD18.7 billion FDI in the same period (Mexican Ministry of Economy, 2020). According to the Mexican Institute of Social Security (IMSS), there are more than 107 thousand OEMs workers and more than 900 thousand in the auto parts sector in Mexico.[5] The IMSS presents official information about the employees of formal private firms in Mexico.

The Northern and the Bajio regions of Mexico employed about 48.4% of the employment workforce in Mexico (i.e., about 510,391 persons) in January 2021.[6] When comparing automotive employment in June 2019 versus June 2020 (the first peak of the pandemic in Mexico), the numbers indicate a loss of 30,376 jobs, from which 65% occurred in the Northern region and 35% in the Bajio region. However, firms in horizontal services, like the MSAs, do not present this correlation. In MSA firms, the loss of employment was 32,676 jobs, 58.1% in the Bajio region and 41.9% in the Northern region.[7] This confirms the findings of Micheli et al. (2017) on the lower dependency of these firms on the economic cycles of the automotive industry, as they address a larger variety of clients with customised products and services. Additionally, the reflected changes in employment suggest that firms in the upper tiers of the production chain negatively impact the industry's employment changes.

Although firms adopted employment management strategies to preserve their workforce in July 2020, labour in the auto industry was reduced by about 5% for June 2020 due primarily to lower automobile sales worldwide.[8] Table 1 presents the changes in employment in the automotive industry, comparing the situation from June 2019 to June 2020. Large auto parts firms and MSAs were the most affected by the pandemic. On average, during the first four months of the pandemic (March–June 2020), auto parts firms reduced their workforce by about 6.8%, while MSAs reduced their workforce by about 4.3%.[9]

Table 1 Employment changes in the automotive sector in the Northern and Bajio regions (June 2019–June 2020)

	OEMs			*Auto parts*			*MSA firms*		
	Small	*Medium*	*Large*	*Small*	*Medium*	*Large*	*Small*	*Medium*	*Large*
June 2019	498	716	53,950	4,812	23,251	412,360	166,431	239,456	393,462
June 2020	627	408	53,703	5,293	25,177	380,164	168,116	237,448	359,564
Jobs changes	129	−308	−247	481	1,926	−32,196	1,685	−2,008	−33,898
Variation (%)	25.9%	−43%	−0.5%	10%	8.3%	−7.8%	1%	−0.8%	−8.6%

Source: Calculated by the authors with data from IMSS (2020)

3 Methodology

This research is based on two independent online surveys addressing manufacturing firms and complemented by information provided by in depth interviews. The interviews were conducted with auto firms' owners and CEOs in Ciudad Juarez (Northern Mexico) and Guadalajara (El Bajio, Mexico) in 2018–2019. The interviews addressed three Tier 1 suppliers (i.e., Bosch, Continental and Aptiv) and Tier 3 and Tier 4 local suppliers (e.g., Repinel, Pima, Mecatronix and Simsa). The interviews provide insights into the relationships between OEMs and their local service suppliers. The interviews sought to identify the innovation and business ecosystem strengths that help automotive firms move into I4.0 technologies and identify bottlenecks preventing this from happening.

The first online survey, named Baja I4.0 (Axis Centro de Inteligencia Estrategica, 2019a), was conducted in Baja California (Northern Mexico) in June 2019, and it addressed manufacturing firms.[10] The auto industry in Baja California is not one of the Mexican auto industry's main hubs (ECLAC, 2018). However, it has Toyota and its first-tier and second-tier suppliers, and the aftermarket's firms segment.

The Baja I4.0 survey was responded to by one person in each firm. The selection criteria required this person to:

1 be an engineer

2 have a job task related to engineering and technical processes, or to be department head, manager, or CEO.

Four departments were involved in responding to the survey, namely manufacturing/production, engineering, quality and supply chain. The Baja I4.0 survey explores the levels of knowledge and understanding of a set of 19 I4.0 technologies in manufacturing firms and their degree of adoption of these I4.0 technologies. The survey uses a point-scale from 0 to 4, where 0 represents null knowledge on the I4.0 technology and four an expert level.[11] This study selected 17 auto parts firms and 49 MSA firms out of the 163 firms from all manufacturing sectors addressed by the Baja I4.0 survey.[12]

The set of 19 I4.0 technologies explored in the Baja I4.0 survey is presented in Table 2. Following Axis Centro de Inteligencia Estrategica (2019b), the selection of these technologies was validated by representatives of the local industry who are members of the National Chamber of Electronics, Telecommunications, and Technologies (CANIETI), which is the leading organisation promoting I4.0 in Baja California.

The second online survey used in this research addresses manufacturing and service firms in several Mexican locations exploring the impact that COVID-19 brought to them during the first months of the pandemic and the strategies adopted to face the situation. This survey was designed and implemented by an inter-organisational research group named GIDI (Grupo de Investigacion Interinstitucional). This online survey was divided into several phases. This research builds upon the second phase of the GIDI survey conducted in September 2020 and addresses the impact that COVID-19 has had on firms after the shutdowns of the first half of 2020 and their adopted strategies to overcome COVID-19 challenges (GIDI, 2020).[13] The survey was responded to by 1,628 manufacturing firms. After selecting automotive firms, this research builds on the response of 40 automotive first-tier suppliers and 132 MSA firms located in the Northern (i.e., Baja California, Sonora, Chihuahua, Coahuila, Nuevo Leon and Tamaulipas) and

Bajio (i.e., Jalisco, Aguascalientes, Guanajuato, Queretaro, San Luis Potosi) regions of Mexico.[14]

Table 2 I4.0 implemented analysed in this research

Intangible
Digital twin
Blockchain
Machine learning/deep learning
Big data analytics
Cloud computing
Virtual reality
Vertical and horizontal systems integration
Cybersecurity
Intelligent energy management
Internet of things
Augmented reality
Advanced simulation/digital modelling
Computer vision/pattern recognition
Collaborative robots (Cobots)
Real-time process monitoring
Sensing and data collection
Autonomous robotics
Automated guided vehicles
Additive manufacturing
Tangible

Note: This classification is illustrative and not exhaustive.

Source: Prepared by the authors based on Axis Centro de Inteligencia Estrategica (2019b, p.42)

4 Results

4.1 I4.0, the perspective from selected firms (interviews)

This section provides insights from interviews with three OEMs and four local MSA firms. The first-tier suppliers interviewed are Aptiv, Bosch and Continental, three of them involved in cars of the future and smart factory (I4.0) projects.

Aptiv is a firm focused on software capabilities, advanced computing platforms and networking architecture. Aptiv, formerly Delphi Automotive, is an automotive supplier of global technology. It designs and produces vehicle components and provides safety technology solutions. It is an active player in electric car manufacturing. Some of its major customers include GM, Volkswagen, Fiat, Hyundai, Ford, BMW and Porsche. Their Mexican subsidiary (i.e., Aptiv Contract Services, S. de RL de CV) is located in

Ciudad Juarez, Chihuahua, in the country's Northern region. Aptiv focuses on providing its clients with autonomous, connected, shared, electric mobility technologies.

The interviews with Bosch and Continental in their Northern and Bajio subsidiaries showed that these OEMs are seriously committed to implementing I4.0 technologies and processes in their production plants. These firms allocate a percentage of their sales to their research and development (R&D) department and have (re)structured departments within their facilities to adopt these technologies. Bosch indicated a reduction of costs, increased efficiency, productivity, and increased control of machines, tools, and people due to a higher implementation of I4.0.

Interviews with domestic MSA firms specialised in developing and integrating I4.0 technologies (i.e., Pima, Repinel Electric, Mecatronix and Simsa) revealed that all these firms are aware and conscious of the forthcoming digital change and the great business opportunity that this may bring to them. They are focused on strengthening projects related to I4.0, and they are focusing on automation of processes through the development or acquisition of artificial intelligence. These four firms are betting on I4.0 transformation and allocating resources to the development of tracing systems, artificial vision systems and additive manufacturing.

The interviews suggested the need for complementarity between global suppliers and MSAs in the national route towards I4.0. Generally speaking, the interviews have found good progress in both first-tier suppliers and MSA firms towards the I4.0 transformation. Global suppliers have advanced in their I4.0 knowledge, structuring, and implementing these technologies in their production plants and products; MSAs have managed to get businesses and increase their credibility to compete for larger projects. However, the interviews found different types of business behaviour among global suppliers and local MSA firms. On the one hand, firms like Bosh and Continental are developing I4.0 technologies and creating knowledge spillovers to their local suppliers. On the other hand, Aptiv is restraining the evolution of local firms due to unfair financial practices.

The interviews have also confirmed that the main barrier to integrating the local counterparts into larger supplying projects is the lack of resources and the absence of support from local and national governments.

4.2 Levels of knowledge and adoption of I4.0 technologies in the auto parts sector in Mexico

When exploring the level of knowledge and understanding among engineers in the surveyed firms, the results show that about 71% of auto parts firms in Baja California have a low level of knowledge and understanding of these technologies. When analysing which specific I4.0 technologies are known in auto firms in the region, the survey results indicate that most engineers have an intermediate understanding of I4.0 technologies. Among the most known technologies are autonomous robots, real-time process monitoring, sensing and data collection, intelligent energy management, 3D printing, advanced simulation and digital modelling, automated guided vehicles and CoBots. The I4.0 technologies most poorly known among firms in Baja California are digital twins and blockchain technologies.

Taking the mean between firms reporting a high versus a low level of adoption of a set of 19 I4.0 technologies, the Baja I4.0 survey indicates that the mean level of adoption of the auto parts sector and MSA firms in this region is below a medium level [see Table 3, column (6)]. The survey results, presented in Table 3 [columns (3) and (4)], indicate that about 56% of auto parts firms in the region have a high level of adoption of I4.0 technologies, while in the MSA firms, about 57% of firms report a low level of adoption of I4.0 technologies. The level of understanding of these technologies is low, as indicated in Table 3, column (1), with about 71% of the responding engineers indicating a low level of knowledge of these technologies in the auto parts firms and 60% in MSA firms.

Table 3 Level of knowledge and adoption of I4.0 technologies in auto parts and MSA firms in Baja California, Mexico (2019)

Sector	*Level of knowledge I4.0 technologies*		*Level of adoption I4.0 technologies*		*Level in the sector (mean)**		*Number of firms*
	Low (1)	*High (2)*	*Low (3)*	*High (4)*	*Knowledge (5)*	*Adoption (6)*	*(7)*
Auto parts	70.6%	29.4%	43.7%	56.3%	0.404	0.391	17
MSA firms	60.4%	39.6%	56.8%	43.2%	0.323	0.410	49
Total	63.1%	36.9%	53.3%	46.7%	0.345	0.405	N = 66

Note: *Level represents an index that goes from 0 to 1, where 0 means the absence of the indicator and 1 is its highest level.

Source: Calculated by the authors with information from the Baja I4 (Axis Centro de Inteligencia Estrategica, 2019a)

When analysing the specific I4.0 technologies known by auto parts firms, the survey results indicate that among the most adopted technologies are:

1 sensing and data collection

2 real-time process monitoring

3 cybersecurity

4 autonomous robots.

Among the technologies adopted in MSA firms, the survey identifies:

1 real-time process monitoring

2 sensing and data collection

3 cybersecurity

4 internet of things

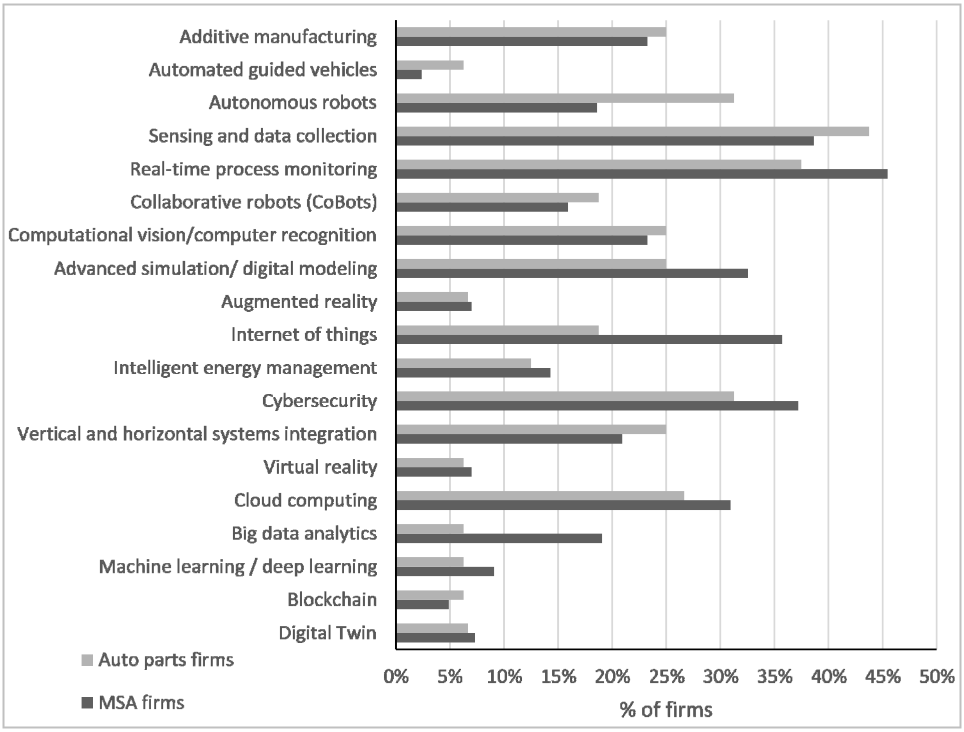
5 cybersecurity

6 cloud computing

7 additive manufacturing (see Figure 2).

Nevertheless, it is important to note that these technologies do not reach half of the sample, with only about 20%–30% of firms adopting these technologies (see Figure 2).

Figure 2 Adoption of I4.0 technologies among auto parts and MSA firms



Source: Calculated by the authors with data from Baja I4.0 (2019a)

When grouping I4.0 technologies by their degree of use complexity and their novelty in the industrial environment, the results indicate that auto firms and MSA firms are more familiar with tangible I4.0 technologies than intangible ones. Table 4 also shows that engineers in these firms are more familiar with I4.0 technologies of lower complexity to the user and those long in the market.

Table 4 I4.0 technologies by type and complexity, auto parts and MSAs firms (2019)

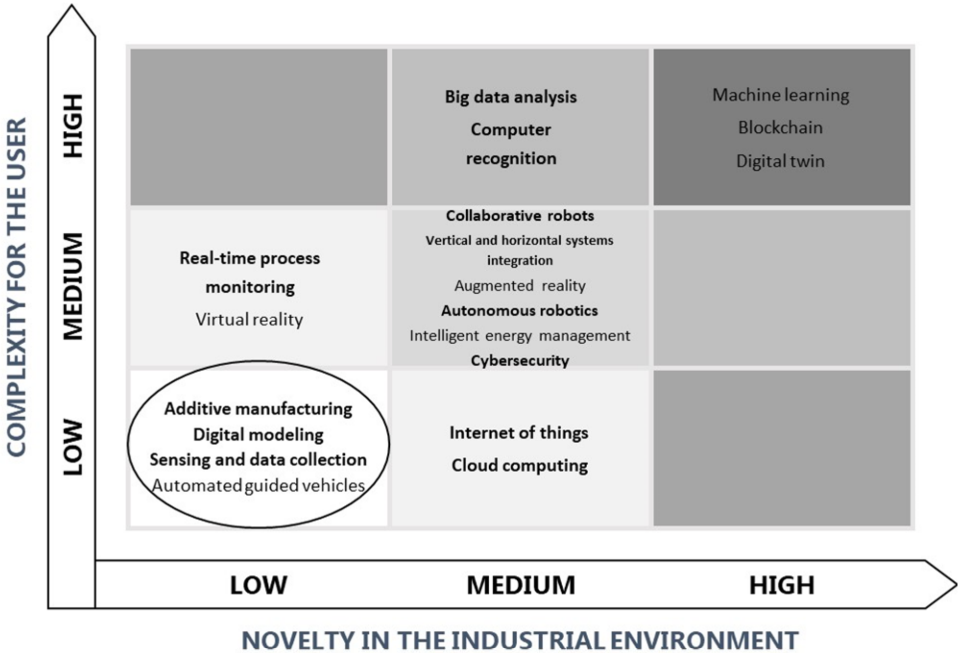
	Group of 19 I4.0 technologies							
Sector	*Type**		*Complexity to the user**			*Novelty**		
	Tangible	*Intangible*	*Low*	*Medium*	*High*	*Low*	*Medium*	*High*
Auto parts	0.46	0.37	0.45	0.42	0.33	0.43	0.43	0.27
Services	0.33	0.32	0.37	0.32	0.27	0.36	0.33	0.23
Average	0.37	0.33	0.39	0.35	0.29	0.38	0.35	0.24

Note: *Data represents an index that goes from 0 to 1, where 0 means the absence of the indicator and 1 is its highest level.

Source: Calculated by the authors with data from Baja I4.0 (Axis Centro de Inteligencia Estrategica, 2019a)

Figure 3 presents an illustration of the relationship between complexity for the user and novelty in the market of the 19 I4.0 technologies analysed in this study.

Figure 3 Relationship between complexity and novelty of I4.0 technologies (see online version for colours)



Source: Elaborated by the authors based on Axis Centro de Inteligencia Estrategica (2019b, p.55)

4.3 The auto industry in Mexico and its resilience to COVID-19

Taking 40 auto parts firms and 132 local MSA firms from the COVID-19 enterprise impact survey (GIDI, 2020), this research analyses how firms in Mexico reacted to the pandemic restrictions. The analysis compares firms in two geographic locations, where most OEMs and automobile investments are located, namely: Mexico's Northern region and the Bajio region. Table 5 presents the impact that the COVID-19 policy restrictions had on the sample firms. Firms in both regions considered the COVID-19 effects as intermediate, with a more substantial effect in the Northern region than in the Bajio region. In the case of the MSA firms, those in the Bajio found the effects severe compared to those in the Northern region, whose general perception was that the effects were intermediate.

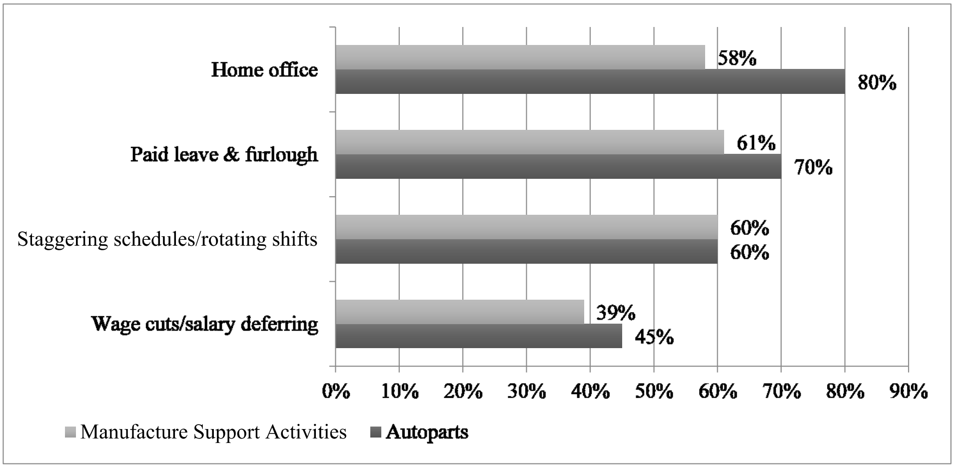
Table 5 COVID-19 impact in automotive firms in Mexico (Northern and Bajio regions)

	Northern region			*Bajio region*		
	Severe	*Intermediate*	*Low*	*Severe*	*Intermediate*	*Low*
Auto parts	25.0%	57.1%	17.9%	20%	80%	0
MSA firms	9.1%	60.2%	30.7%	50%	18.8%	31.2%

Source: Calculated by the authors with data from GIDI (2020, Phase II)

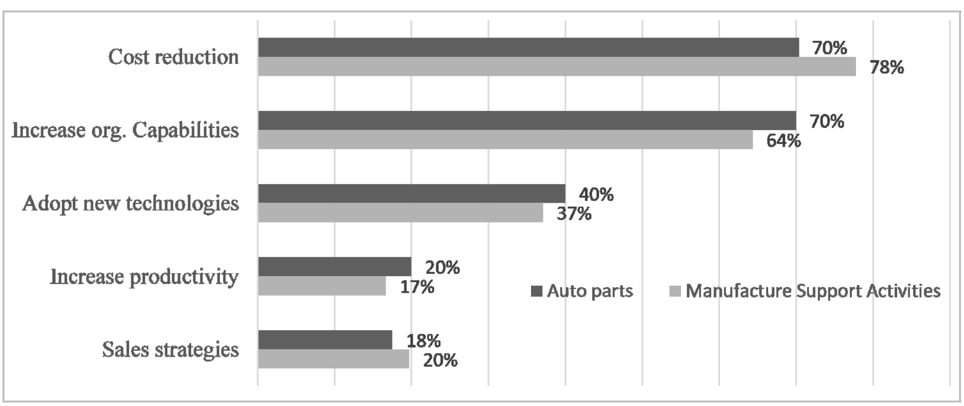
The GIDI (2020) survey finds that automotive and MSA firms adopted workforce management strategies with more intensity than technological options to face the COVID-19 challenges (see Figure 4). The three most common strategies identified are home office (80% of firms), paid leave and furlough (70% of firms), and rotating working schedules (about 60% of firms). The same strategies were present in MSA firms.

Figure 4 Workforce management strategies adopted under COVID-19 (October 2020)



Source: Elaborated by the authors with information from GIDI (2020, Phase II)

Figure 5 Mitigation strategies under COVID-19 (October 2020)



Source: Elaborated by the authors with information from GIDI (2020, Phase II)

The findings presented in Figure 4 are in line with those indicated by Ornelas (2021), who indicates that the Mexican Government required including vulnerable workers in production lines under COVID-19, resulting in expensive substitution and rotating schemes. Figure 4 indicates that 45% of auto parts firms and 39% of MSA firms adopted wage cuts and deferred salaries. Apedo-Amah et al. (2020) find that wage cuts were adopted by about 30%–40% of manufacturing firms independent of their size. This indicates that Mexican firms are behaving in a similar way to firms in other countries.

Figure 5 indicates that about 70% of auto parts firms focused on cost reduction and increase their organisational capabilities, while about 78% of MSA firms focused on reducing their costs and about 64% on increasing their organisational capabilities. The results also indicate that the adoption of new technologies was only explored for about 40% of auto part firms and 37% of MSA firms.

When analysing workforce management strategies by region, the research finds that automotive firms in both regions focused strongly on workforce management strategies, rather than engineering solutions, to face the economic effects of COVID-19. Nevertheless, the Northern region had a slightly higher tendency towards engineering solutions than the Bajio region. When the firms were asked about the government's support in facing the pandemic's economic challenges, only one auto parts firm, and 8% of the MSA firms surveyed had access to some support. However, most of this support was focused on solving issues of salaries and wages. No support from the government was reported in enhancing the use of better technologies in firms.

Regarding the expected time of economic recovery, most firms indicated that they would need more than a year to recover from the losses that the shutdowns have brought them. The data indicates that while auto parts firms in the Northern region of Mexico estimate a recovery in about 14 months, auto parts firms in the Bajio estimated around 17.8 months. MSA firms in the Northern region estimated a recovery time of about 14.6 months versus 17.2 months for those in the Bajio region.[15] The results suggest that the region in which the firm is located greatly influences their expected recovery, more than the economic activity. This is in line with the literature findings that the impact of COVID-19 in the economic sector varies according to regional heterogeneity and growth rates across regions (Demirbag et al., 2020; Shen et al., 2021).

5 Discussion of findings

Due to its high level of globalisation and technological complexity, the auto industry has always been an essential sector in shaping industrial development and growth. For the Global South, hosting automotive production includes OEMs and different level suppliers with various degrees of product complexity. This ecosystem of auto firms provides important employment for the local economy and pushes for learning and innovation within the national system.

This study explores the perspective of domestic auto parts firms in the Global South context. The research interviews indicate that European firms, such as Bosch and Continental, have a high level of engagement towards I4.0 technologies. They have R&D departments that focus on I4.0 manufacturing activities. Interviews with first-tier suppliers and MSA firms in Ciudad Juarez and Guadalajara indicate a higher level of interest in adopting these technologies.

The analysis of the Baja I4.0 data indicates that the level of knowledge of I4.0 technologies among auto parts firms in the region is limited and that only about 20%–30% of firms have started to adopt one of these technologies. The results of for this region indicate that auto firms and MSA firms are more familiar with tangible I4.0 technologies (i.e., CoBots, sensors, monitoring processes) than intangible ones (i.e., digital twins and blockchain). Preference is given to those technologies which are simpler to operate for users. The Baja I4.0 survey shows that the local counterpart supporting this process lacks or has weak human capital to integrate into this technological path. As indicated by Brynjolfsson and Hitt (2000) and Brynjolfsson et al. (2019), the intangibles complement tangibles in improving productivity. Therefore, automotive firms' efforts to seek new talent, training internally, and improve their workforce competencies are fundamental in the race towards I4.0.

COVID-19 disrupted the automotive industry's growth trend, as it affected the global demand for automobiles due to mobility restrictions, and it also negatively affected firms' profitability, bringing high unemployment levels. Although COVID-19 is a phenomenon independent from the planned rate of adoption of I4.0 technologies, the literature has shown that in the auto industry, it has pushed forward their adoption as a mechanism to overcome the effects of COVID-19 (Accenture, 2020; Acioli et al., 2021; Belhadi et al., 2021). The GIDI data analysis results show that Mexican firms have focused on workforce management strategies to reduce costs rather than engineering solutions like accelerating the adoption of new I4.0 technologies. This is particularly critical at a time when the worldwide supply chain disturbance has made firms reorganise themselves to have a more efficient workforce, lower costs and new technologies (Covarruvias, 2018; Covarruvias and Ramirez, 2020).

This disparity between speed and levels of adoption among different tiers and levels of the automotive pyramid could be understood from the capacity-building literature perspective when exploring the adoption of lean production processes in the early 1990s (Janoski and Lepadatu, 2021). As in the case of lean production, some I4.0 technologies will be adopted as best practices and will be adopted broadly. Currently, most firms are experimenting with some of these technologies in specific areas with limited resources, and only some firms are experimenting more comprehensively and extensively with the support of their headquarters, subsidiaries and local suppliers. Despite the lack of governmental support, weak innovation systems, and weak institutional environment, the interviews indicate that OEMs and first-tier suppliers are adopting I4.0 technologies in their subsidiaries worldwide (including Mexico).

6 Future research paradigms

COVID-19 has been an external shock that has forced the automotive industry to rethink its speed of adopting I4.0 technologies. There is no doubt that OEMs and Tier 1 integrator systems firms will redesign their value chains and supply chains in the coming years, as already planned under I4.0. The pandemic has accelerated the adoption of online (remote) working worldwide and promoted an increase in digitalisation and automation in production. The actual effects on the substitution of work, and the economic-social trade-offs associated with technological change are still to be seen; however, these are aspects outside the scope of the available data and this research.

In the Mexican auto industry case, we identify three challenges that will determine its reorganisation and integration into the worldwide supply chain. First, the impacts of COVID-19 on the global economy have shown the low levels of readiness of firms to react to major global disruptions and the critical relevance of digital technologies in manufacturing production. Second, the new set of duty rules imposed by the USMCA adds to the factors that the automotive industry in Mexico needs to adjust to. Third, the industry's worldwide transition towards electric vehicles requires the simplification of the value chain and a higher level of technology in the supply chain's composition. These three aspects are great challenges to the industry and require future research and analysis.

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References

Accenture (2020) *Impact on the Automotive Industry: Navigating the Human and Business Impact of COVID-19*, Accenture [online] https://www.accenture.com/_acnmedia/PDF-121/Accenture-COVID-19-Impact-Automotive-Industry.pdf (accessed 27 February 2021).

Acioli, C., Scavarda, A. and Reis, A. (2021) 'Applying Industry 4.0 technologies in the Covid-19 sustainable chains', *International Journal of Productivity and Performance Management*, ahead of print [online] https://doi.org/10.1108/IJPPM-03-2020-0137.

Apedo-Amah, M.C., Avdiu, B., Cirera, X., Cruz, M., Davies, E., Grover, A., Iacovone, L., Kilinc, U., Medvedev, D., Maduko, F.O., Poupakis, S., Torres, J. and Tran, T.T. (2020) *Unmasking the Impact of Covid-19 on Businesses: Firm-level Evidence from Across the World*, World Bank Group, Finance, Competitiveness and Innovation Global Practice, 9434, Washington, DC.

Autor, D., Mindell, D. and Reynolds, E. (2020) *The Work of the Future. Building Better Jobs in an Age of Intelligent Machines*, Report, Massachusetts Institute of Technology, Cambridge, MA [online] https://workofthefuture.mit.edu/research-post/the-work-of-the-future-building-better-jobs-in-an-age-of-intelligent-machines/ (accessed 9 March 2021).

Axis Centro de Inteligencia Estrategica (2019a) *Baja I4.0 [Firm Level Survey to Firms in Baja California on I4.0 Technologies]*, Axis Centro De Inteligencia Estrategica [Database], Tijuana, Baja California.

Axis Centro de Inteligencia Estrategica (2019b) *Baja I4.0*, Report, Axis, Tijuana, Baja California [online] https://vp.inteliaxis.com/PDF/Bajai40.pdf (accessed 20 February 2021).

Belhadi, A., Kamble, S., Jabbour, C.J.C., Gunasekaran, A., Ndubisi, N.O. and Venkatesh, M. (2021) 'Manufacturing and service supply chain resilience to the Covid-19 outbreak: lessons learned from the automobile and airline industries', *Technological Forecasting & Social Change*, Vol. 163 [online] https://doi.org/10.1016/j.techfore.2020.120447.

Brincks, C., Domanski, B., Klier, T. and Rubenstein, J.M. (2018) 'Integrated peripheral markets in the auto industries of Europe and North America', *International Journal of Automotive Technology and Management*, Vol. 18, No. 1, pp.1–28 [online] https://doi.org/10.1504/IJATM.2018.090170.

Brynjolfsson, E. and Hitt, L.M. (2000) 'Beyond computation: information technology, organizational transformation, and business performance', *Journal of Economic Perspectives*, Vol. 14, No. 4, pp.23–48 [online] https://doi.org/10.1257/jep.14.4.23.

Brynjolfsson, E., Rock, D. and Syverson, C. (2019) 'Artificial intelligence in the modern productivity paradox: a crash of expectations and statistics', in Agrawal, A., Gans, J. and Goldfarb, A. (Eds.): *The Economics of Artificial Intelligence: An Agenda*, pp.23–57, University of Chicago Press.

CANIETI (2017) *Estudio De Diagnostico E Identificacion De Oportunidades De Desarrollo De La Industria Electronica De Baja California*, Report, Secretaria de Economia, Mexican Chamber for the Electronics, Telecommunications, and Information Technology Industries [online] https://www.gob.mx/cms/uploads/attachment/file/311904/PPCI-2016080489_-_Estudio_de_diagn_stico.pdf (accessed 20 February 2021).

Carrillo, J. and Contreras, O. (2008) 'The historical evolution of American auto firms in Mexico. Two models of local development', *International Journal of Automotive Technology and Management*, Vol. 8, No. 4, pp.382–400 [online] https://doi.org/10.1504/IJATM.2008.02031.

Carrillo, J. and Matus, M. (2020) 'Will the Mexican auto parts Maquilas be able to transit to I4.0?', *Paradigma Economico*, Vol. 12, No. 2, pp.39–61.

Carrillo, J. and Rodriguez, A.B. (2020) 'Heterogeneidad En Las Afectaciones a Las Empresas: Indicadores, Tendencias Y Diferencias En La Escala Nacional of Work', Paper presented at *Foro de análisis "Impacto del COVID-19 en las Empresas Mexicanas. Análisis de sectores y regiones"*, Tijuana, Baja California, Mexico, 17 November.

Carrillo, J., Gomis, R., de los Santos, S., Covarruvias, L. and Matus, M. (2020) 'Podran Transitar Los Ingenieros a La Industria 4.0? Analisis Industrial En Baja California (Are engineers able to move towards Industry 4.0 in the automotive sector? The case of Baja California, Mexico)', *Entreciencias: Dialogos en la Sociedad del Conocimiento*, Vol. 22, No. 13, pp.1–22 [online] http://dx.doi.org/10.22201/enesl.20078064e.2020.22.76089.

CEPAL (2020) *La Inverstion Extranjera Directa En America Latina Y El Caribe 2020*, LC/PUB.2020/15-P, Comision Economica para America Latina y el Caribe (CEPAL), Santiago, Chile.

Chaabane, O. (2018) *The Global South and the Challenge of the "Fourth Industrial Revolution"*, 21 March, TRT World.

Chinoracky, R., Turska, S. and Madlenaroka, L. (2020) 'Does Industry 4.0 have the same impact on employment in the sectors?', *Management*, Vol. 14, No. 1, pp.5–17 [online] https://doi.org/10.26493/1854-4231.14.5-17.

Contreras, O., Carrillo, J. and Alonso, J. (2012) 'Local entrepreneurship within global value chains: a case study in the Mexican automotive industry', *World Development*, Vol. 40, No. 5, pp.1013–1023 [online] https://doi.org/10.1016/j.worlddev.2011.11.012.

Corona, F., Solis, V. and Hernandez, V. (2020) *Actividad Económica De México En Abril 2020. Resultados De Nowcasting Y De La Matriz De Contabilidad Social*, Report, INEGI, Mexico.

Covarruvias, A. (2018) 'When disruptors converge: the last automobile revolution', *International Journal of Automotive Technology and Management*, Vol. 18, No. 2, pp.81–104 [online] https://doi.org/10.1504/IJATM.2018.092184.

Covarruvias, A. and Ramirez, S.M.P. (Eds.) (2020) *New Frontiers of the Automobile Industry. Exploring Geographies, Technology, and Institutional Change*, Palgrave Macmillan, New York.

Dachs, B., Kinkel, S. and Jager, A. (2019) 'Bringing it all back home? Backshoring of manufacturing activities and the adoption of Industry 4.0 technologies', *Journal of World Business*, Vol. 54, No. 6, pp.1–15 [online] https://doi.org/10.1016/j.jwb.2019.101017.

Demirbag, M., Glaister, K. and Sengupta, A. (2020) 'Which regions matter for MNEs? The role of regional and firm level differences', *Journal of World Business*, Vol. 55, No. 1 [online] https://doi.org/10.1016/j.jwb.2019.101026.

Deng, L., Plumpe, V. and Stegmaier, J. (2021) *Robot Adoption at German Plants*, VOX EU [online] https://voxeu.org/article/robot-adoption-german-plants (accessed 23 February 2021).

ECLAC (2018) *Foreign Direct Investment in Latin America and the Caribbean*, LC/PUB.2018/13-P, Economic Commission for Latin America and the Caribbean, Santiago, Chile.

Fareri, S., Fantoni, G., Chiarello, F., Coli, E. and Binda, A. (2020) 'Estimating Industry 4.0 impact on job profiles and skills using text mining', *Computers in Industry*, June, Vol. 118 [online] https://doi.org/10.1016/j.compind.2020.103222.

Frey, C.B. and Osborne, M.A. (2017) 'The future of employment: how susceptible are jobs to computerisation?', *Technological Forecasting and Social Change*, Vol. 114, pp.254–280 [online] https://doi.org/10.1016/j.techfore.2016.08.019.

Gehl-Sampath, P. and Vallejo, B. (2018) 'Trade, global value chains and upgrading: what, when and how?', *The European Journal of Development Research*, Vol. 30, No. 3, pp.481–504 [online] http://dx.doi.org/10.1057/s41287-018-0148-1.

GIDI (2020) *Survey on Impacts of the Health Emergency (COVID-19) on Firms in Selected Regions in Mexico. Phases I and II, [Database]*, Tijuana, Baja California.

Gil-Alana, L.A. and Monge, M. (2020) 'Crude oil prices and Covid-19', *Research Letters*, Vol. 1, No. 1, pp.1–4 [online] https://doi.org/10.46557/001c.13200.

Goel, S., Hawi, S., Goel, G., Thakur, V.K., Agrawal, A., Hoskins, C., Pearce, O., Hussain, T., Upadhyaya, H.M., Cross, G. and Barber, A.H. (2020) 'Resilient and agile engineering solutions to address societal challenges such as Coronavirus pandemic', *Materials Today Chemistry*, Vol. 17 [online] https://doi.org/10.1016/j.mtchem.2020.100300.

Gomis, R., Hualde, A. and Matus, M. (2021) 'Escalamiento Digital En Las Pymes Tecnológicas', in Contreras, O. (Ed.): *Pequeñas Empresas Mexicanas En Cadenas Globales De Valor*, Universidad de Sonora, Universidad de Guanajuato, and El Colegio de la Frontera Norte, Mexico.

Guan, D., Wang, D., Hallegatte, S., Huo, J., Li, S., Bai, Y., Lei, T., Xue, Q., Davis, S.J., Coffman, D.M., Cheng, D., Chen, P., Liang, X., Xu, B., Lu, X., Wang, S., Hubacek, K. and Gong, P. (2020) *Global Economic Footprint of the Covid-19 Pandemic*, Tsinghua University, Beijing.

Guzman-Anaya, L. (2020) *Mexico's Automotive Industry Post COVID-19*, Pacific Economic Cooperation Council,

Hausler, S., Heineke, K., Hansley, R., Moller, T., Schwedhelm, D. and Shen, P. (2020) *The Impact of COVID-19 on Future Mobility Solutions. As the Global Pandemic Spreads, Mobility Players Need to Prepare for the New World Ahead*, Report, McKinsey Center for Future Mobility [online] https://www.mckinsey.com/~/media/McKinsey/Industries/Automotive%20and%20Assembly/Our%20Insights/The%20impact%20of%20COVID-19%20on%20future%20mobility%20solutions/The-impact-of-COVID-19-on-future-mobility-solutions-vF.ashx (accessed 27 February 2021).

Hirsch-Kreinsen, H. (2016) 'Digitalization of industrial work: development paths and prospects', *Journal of Labour Market Research*, Vol. 49, pp.1–14 [online] https://doi.org/10.1007/s12651-016-0200-6.

Hofstatter, T., Krawina, M., Muhlreiter, B., Pohler, S. and Tschiesner, A. (2020) *Reimagining the Auto Industry's Future: It's Now or Never*, Report, McKinsey & Company [online] https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/reimagining-the-auto-industrys-future-its-now-or-never (accessed 27 February 2021).

IMSS (2020) *Open Data of Workers in Social Security*, IMS, Mexico City [online] https://datos.imss.gob.mx/group.asegurados (accessed 2 March 2021).

Iyke, B.N. (2020) 'The disease outbreak channel of exchange rate return predictability: evidence from Covid-19', *Emerging Markets Finance and Trade*, Vol. 56, No. 10, pp.2277–2297 [online] https://doi.org/10.1080/1540496X.2020.1784718.

Janoski, T. and Lepadatu, D. (Eds.) (2021) *The Cambridge International Handbook of Lean Production. Diverging Theories and New Industries Around the World*, Cambridge University Press, Cambridge, UK.

Kagermann, H., Wahlster, W. and Helbig, J. (2013) *Securing the Future of German Manufacturing Industry. Recommendations for Implementing the Strategic Initiative Industrie 4.0*, Final Report of the Industrie 4.0 Working Group, National Academy of Science and Engineering [online] https://www.din.de/blob/76902/e8cac883f42bf28536e7e8165993f1fd/recommendations-for-implementing-industry-4-0-data.pdf (accessed 27 February 2021).

Kinkel, S. (2018) 'Industry 4.0 application and reshoring of manufacturing – evidence, limitations, and policy implications of work', Paper presented at *MAKERS Workshop 'Industry 4.0 – Implications for an EU Industrial Policy'*, Brussels, Belgium, 25 January.

Koenig, B. (2020) *Auto Industry Gets Back into Gear Following Covid-19 Shutdown*, SME Media [online] https://www.sme.org/technologies/articles/2020/september/auto-industry-gets-back-into-gear-following-covid-19-shutdown/ (accessed 23 February 2021).

Krzywdzinski, M. (2020) *Automation, Digitalization, and Changes in Occupational Structures in the Automobile Industry in Germany, the United States, and Japan: A Brief History from the Early 1990s Until 2018*, Weizenbaum Institute for the Networked Society – The German Internet Institute, 10, Berlin.

Lampon, J.F., Cababelas, P. and Guzman, J.A.D. (2018) 'Claves En La Evolucion De Mexico Dentro De La Cadena De Valor Global De La Industria De Autopartes. El Caso Del Bajio', *El Trimestre Economico*, Vol. 85, No. 339, pp.483–514 [online] https://doi.org/10.20430/ete.v85i339.259.

Lara, A., Garnica, A.G. and Trujano, G. (2004) 'Diseno Modular Y Cadena De Suministro En El Sector Autopartes: Caso De Lear Corporation', in Juarez, H., Lara, A. and Bueno, C. (Eds.): *El Auto Global, Desarrollo, Competencia Y Cooperacion De La Industria Del Automovil*, UAM-BUAP-IBERO-Conacyt, Mexico.

Lee, K-F. (2019) *AI Superpowers – China, Silicon Valley, and the New World Order*, Houghton Mifflin Harcourt, Boston, MA.

Llopis-Albert, C., Rubio, F. and Valero, F. (2021) 'Impact of digital transformation on the automotive industry', *Technological Forecasting & Social Change*, Vol. 162 [online] https://doi.org/10.1016/j.techfore.2020.120343.

Matus, M. and Carrillo, J. (2021) *Las Pymes Intensivas En Conocimiento En Ciudad Juarez: Diversidad De Trajectorias, Practicas Y Emprendimientos Sobre La I4.0*, January–December, Frontera Norte, in press.

Mexican Ministry of Economy (2020) *Inversión Extranjera Directa. Reporte Estadísticos De Ied. Información Estadística De Flujos De Ied Hacia México Por Entidad Federativa Desde 1999 (Foreign Direct Investment. Statistical Report of FDI. Statistical Information of FDI Flows Towards Mexico by State Since 1999)*, Report, Gobierno de Mexico (Mexican Government) [online] https://www.gob.mx/se/acciones-y-programas/competitividad-y-normatividad-inversion-extranjera-directa?state=published (accessed 2 March 2021).

Micheli, J., Carrillo, J. and de los Santos, S. (2017) 'The auto OEMs impact on local development. The case of knowledge intensive services in Mexico of work', Paper presented at *25th International Colloquium of Gerpisa*, Paris, 14–16 June.

OICA (2020) *Production Statistics 2019*, Database [online] https://www.oica.net/category/production-statistics/2019-statistics/ (accessed 2 March 2021).

Ornelas, S.L. (2021) *The Texas-Mexico Automotive Connection. A Tale of Cooperation and Competitiveness*, March–April, Vol. 111 [online] https://mexico-now.com/mexiconow-magazine-march-april-2021/.

Rodriguez-de la Fuente, M. and Lampon, J.F. (2020) 'Regional upgrading within the automobile industry global value chain: the role of the domestic firms and institutions', *International Journal of Automotive Technology and Management*, Vol. 20, No. 3, pp.319–340.

Schneider, N. (2017) 'Between promise and skepticism: the global south and our role as engaged intellectuals', *The Global South as Subversive Practice*, pp.18–38, Indiana University Press, Bloomington, IN.

Schwab, K. (2017) *The Fourth Industrial Revolution*, World Economic Forum.

Shen, H., Fu, M., Pan, H., Yu, Z. and Chen, Y. (2021) 'The impact of Covid-19 pandemic on firm performance', *Emerging Markets Finance and Trade*, Vol. 56, No. 10, pp.2213–2230 [online] https://doi.org/10.1080/1540496X.2020.1785863.

Sumer, B. (2018) 'Impact of Industry 4.0 on occupations and employment in Turkey', *European Scientific Journal*, Vol. 14, No. 10, pp.1–17 [online] https://doi.org/10.19044/esj.2018.v14n10p1.

Szalavetz, A. (2019) 'Industry 4.0 and capability development in manufacturing subsidiaries', *Technological Forecasting and Social Change*, August, Vol. 145, pp.384–395 [online] https://doi.org/10.1016/j.techfore.2018.06.027.

UNCTAD (2020) *World Investment Report 2020. International Production Beyond the Pandemic*, United Nations Conference on Trade and Development, Geneva.

Vallejo, B. (2010) *Learning and Innovation under Changing Conditions. The Auto Parts Industry in Mexico*, PhD, Maastricht University.

Vallejo, B. (2017) 'Trayectorias Tecnologicas Existentes Y Emergentes Hacia 2020. Una Panoramica a La Industria Automotriz Global (Existing and emerging technological trajectories towards 2020. A birdview of the global automotive industry)', in Martinez Martinez, A. and Carrillo Viveros, J. (Eds.): *Innovacion, Redes De Colaboracion Y Sostenibilidad. Experiencias Regionales Y Tendencias Internacionales De La Industria Automotriz*, UNAM, Colson and CIAD, Mexico City and Hermosillo.

Zhong, R., Xu, Y., Klotz, E. and Newman, S.T. (2017) 'Intelligent manufacturing in the context of Industry 4.0. A review', *Engineering*, Vol. 3, No. 5, pp.616–630 [online] https://doi.org/10.1016/J.ENG.2017.05.015.

Notes

1 The term Global South is accepted in the development literature as a more open and value-free alternative to the terms third-world or developing countries. More can be read at Schneider (2017).

2 Currently, industrial digital platforms are not interacting with e-commerce platforms. Only recently brands like VW, Ford, and Volvo have announced the intent to remove intermediaries or dealers (https://europe.autonews.com/automakers/why-vw-ford-volvo-others-are-accelerating-shift-online-sales-europe).

3 https://auto.economictimes.indiatimes.com/news/industry/vw-ceo-expects-software-to-make-up-90-percent-of-auto-industry-innovation/68384527.

4 The report refers to six percentage-point decrease (Hofstatter et al., 2020). The authors made a calculation to present the information in terms of percentage as the data presented in this study.

5 Calculations made by the authors based on data from the IMSS database (http://datos.imss.gob.mx/group/asegurados).

6 Ibid.

7 Ibid.

8 Ibid.

9 Ibid.

10 Research based on Axis Centro de Inteligencia Estrategica (2019a) could be seen at Matus and Carrillo (2021), Carrillo and Matus (2020) and Carrillo et al. (2020).

11 0 = null level of knowledge, 1 = basic knowledge, 2 = intermediate level, 3 = sufficient level and 4 =e xpert level.

12 Baja California's automotive industry includes more than 80 firms mostly focused on parts and components for OEMs and the aftermarket (Carrillo et al., 2020). Most of these firms are American, with a low presence of European or Asian firms.

13 Research based on GIDI (2020) could be seen at Gomis et al. (2021).

14 There is no overlapping from those firms analysed by Baja I4.0.

15 The scarce availability of semiconductors felt in March–April 2020 will probably delay the recovery of the auto sector in Mexico.