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**Digital upgrade in the automotive supply chain in Mexico:
issues and challenges**

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Abstract

The ongoing digital transformation poses diverse challenges to the automotive sector. While the process of digitalisation will lead to technical and organisational changes across and within the global value chains, the ongoing changes in the trade agreements spurred by the Trump administration may change the location advantages of previous plants and their specialisations. In addition, investment in the electric car may offer first-mover advantages in markets, while requiring the re-organisation of the value chains. Mexico, ranked in 2018 as the seventh producer at world level, is an important case study for several reasons: among these, its cost advantages, its privileged access to the US market, that attracted many OEMs from Europe, Asia, the US, and its role in the prospective regionalization of world trade. By using interviews to automotive suppliers, experts and business associations of the automotive industry, the paper aims at providing a first outline on issues to be addressed in an analysis looking at how these changes are affecting opportunities for the OEMs in their value chains based in the Mexican automotive system.

Key words: company trajectories; profit strategies and product policies; productive organizations; product architectures; organizations and governance; global and regional value chains; platform economy; automotive industry.

JEL: L16, L22, L62, L62, N66, O14, O33

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Without the generous help of several people, this research would have not been possible. In particular, we wish to thank: the participants at the meetings and to the one-to-one interviews with business associations (AMIA, Canacintra, INA), public agencies (InnovaUNAM, ITA, JETRO), the two experts Professor Mónica Casalet (Flacso México) and Professor Carlo Panico (UNAM), the eleven managers (in the purchasing, production, R&D, human resources, logistics functions) of the interviewed companies. Two students assisted the research team: Roberta Avasto, who revised the transcriptions and implemented some coding, Antonio Froio, who cleaned and revised the list of entities. Pietro Passarelli introduced the research team to the adoption of Autoedit.

A special support to the research team has been provided by Aline Mackissack, who flanked Anna and Margherita with attention and curiosity, and to Bertha Maldonado, who answered the countless questions of Anna and Margherita on the economic, political and social conditions in Mexico that the research gradually opened up.

Introduction

The automotive industry is one of the most important industries in many industrialised countries. With over 20,000 parts in a vehicle, sourced from thousands of global suppliers, the automotive supply chain is among the most complex in the world. Major technology trends, such as autonomous driving, electrification, car connectivity and multi-modality will, according to predictions, drive the biggest transformation of the industry since the invention of the automobile in 1885.

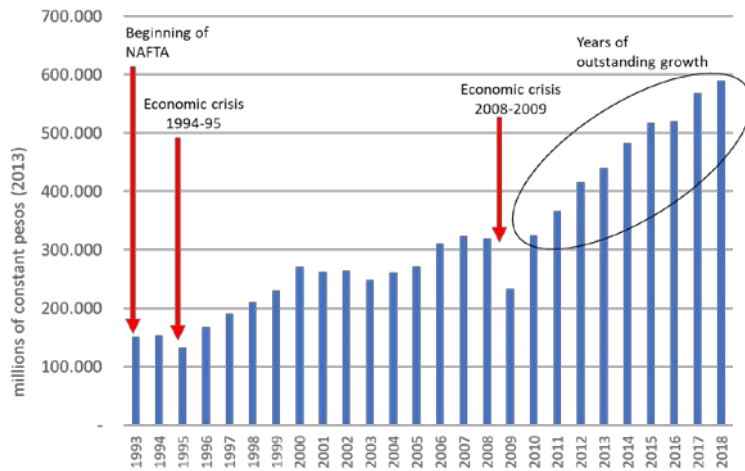
The ongoing digital transformation poses diverse challenges to the automotive sector. While the process of digitalisation will lead to technical and organisational changes across and within the global value chains, the ongoing changes in the trade agreements spurred by the Trump administration may change the location advantages of previous plants and their specialisations. In addition, investment in the electric car may offer first-mover advantages in markets, while requiring the re-organisation of the value chains. The paper aims at providing a first answer to these issues, by looking at how these changes are affecting opportunities for the OEMs in their value chains based in the Mexican automotive system. Mexico, ranked in 2018 as the seventh producer at world level, is an important case study for several reasons: among these, its cost advantages and its privileged access to the US market, that attracted many OEMs from Europe, Asia, the US, and its role in the prospective regionalization of world trade.

The paper addresses two main issues. The first one is the impact of the new trade agreement with US and Canada: its effects inside the country and its cross-country impact on the automotive global value chain; the cross industry transformation and competence networks within the country. A second issue focus on the impact of the digital technological transformation: its quantitative and qualitative impact on labour skills, and the potential linkages of such transformation across other sectors in the Mexican economy.

Overview of the automotive industry in Mexico

The Mexican automotive industry has been growing after NAFTA, and a significant upsurge of production has been recorded also after the crisis of 2009 (Figure 1). It now represents a relevant share in the Mexican economy, both in term of employment and as a share of GDP (Carreto, 2019). About 50% corresponds to the auto parts production: in the last ten years, all the global players in the automotive supply chain have located their operations and main suppliers in various states in Mexico, as witnessed by figures on FDI (Figure 2). According to Industria Nacional de Autopartes (INA), in Mexico there are approximately 600 tier-1 suppliers that support OEM to comply with the trade regulation on regional content (see Figures 2 and 3): of the top 100 global parts suppliers, 90% has plants in Mexico, 1% are Mexican companies, with only 9%, mostly Chinese companies, do not have locations in Mexico.

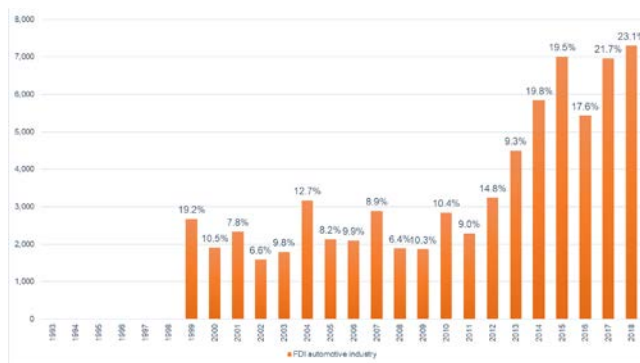
Figure 1 – Manufacturing of transport equipment in Mexico, 1993-2018



Source: INEGI. Sistema de Cuentas Nacionales de México

Figure 2 – FDI in the automotive industry, 1999-2018

Absolute values (vertical axis) and percentage of total FDI (figure above the bar)



Source: INEGI. Sistema de Cuentas Nacionales de México

Figure 3 – Global players in the automotive supply chains that started operations in Mexico



Source: Industria Nacional de Autopartes

The ongoing digital transformations and the changing terms of trade are then a core issue for their impact on the economy and society in Mexico.

Scholars who study the automotive industry in Mexico have focused on several aspects: from maquiladoras to the current changes in the international trade flows. Many studies focus on the domestic demand (renewal of the stock of cars and role of financialization to increase the demand by Mexican users). There is still scant literature on a crucial shift challenging the Mexican companies: the change in trade conditions with US and Canada, and the digital transformation¹.

What makes the analysis of the Mexican automotive industry relevant is that companies supplying auto components are entering a virtuous circle of upgrading their technologies and competences, which is needed to be confirmed as suppliers of the car makers, and possibly to broad their supply to other sector (such as the aerospace industry). In turn, these changes might drive complementary changes in other related industries (e.g. truck and aerospace industries), contributing to a diffusion of digital technologies in many diverse sectors of the economy (from manufacturing, to retail and industrial services).

Some critical areas of change deserve attention, namely, the creation of appropriate skills (in all domains: from software development to data analytics), the retention of trained workers; the needed specific logistic and transport infrastructures; the digital infrastructure that will support 5G.

These changes will not be limited to automotive sector and could provide new impetus to other transformation in the Mexican economy, from manufacturing to services, a path which is observed in other countries (such as Thailand, or South Africa), strongly supported by national policies.

Research Questions

Preliminary findings emerging from desk analysis and field work undertaken by the research team (Carreto Sancinés, 2019; Russo, 2019) show the importance of the analysis of the transition phase in the digital transformation in Mexico (Klier and Rubenstein, 2017). The core research questions focus on two interrelated issues: technical and organizational changes and trade agreements.

With regard to technical changes and their interactions with changing location opportunities, the following questions arise on the ongoing changes in the industrial structure of and the skills required by producers of automotive components located in Mexico:

- What are the main differences in digital technology adoption across actors in the automotive industry supply chain (car makers, 1st tier suppliers, small suppliers)? (i.e. to what extent the different digital technologies are adopted by different actors)
- In what ways is digital transformation changing innovation processes of car makers and automotive suppliers? For example, how is digital transformation changing: the speed of innovation (i.e., changes in innovation cycles); requirements for workforce capabilities and skills; organisational structures?

¹ In a recent report published by (OECD, 2019) there is a focus on the ongoing changes in the automotive supply chains, but no information is available on Mexico.

- How is digital transformation changing firms' patterns of collaboration with other actors (e.g. research institutions, other firms) for innovation?
- Do these changes (IT) make localization more or less fluid when there are changes in localization benefits?

In addressing these questions, a complementary issue must be considered, namely, the current policies supporting the ongoing transformation. Which industrial and research policies, and which training policies would be more appropriate to accelerate the pace of change? Which policies could target young people as carriers of new knowledge? Which policies could be effective for retaining workforce. To which extent a more coordinated and systemic multilevel (i.e. at state and country level) policy would enhance socioeconomic support to the country's opportunities opened by the digital transformation?

Methodology design, data, methods and tools for the empirical analysis

The investigation of the cross industry transformation and competence networks within Mexico is grounded on the conceptual framework of system transformation (Geels, 2004) and complex innovation theory (Lane, 2011).

The research design builds on desk analysis of the supply chains and trade agreements, and on interviews with suppliers, with experts and with business associations of the automotive industry. Abductive reasoning (Agar, 1996, 2006) is adopted to combine multiple sources: data collected through desk analysis of the supply chains and trade agreements, data from secondary sources on plant location, specializations, domestic production/export/import, costs (labour, input, transport), and information collected from interviews with suppliers, with experts and with business associations of the automotive industry.

Semi-structured interviews are an essential first-hand source of updated information to assess the impact of technological change and product innovations on the Mexican automotive industry. The research focuses on tier-1 and tier-2 suppliers in the main segments of the automotive supply chain, and on their customers. The literature on the automotive industry (Helper and Sako, 2010; Sturgeon, Van Biesebroeck and Gereffi, 2008) highlights that the various OEMs have different strategies in organizing their value chains. This perspective is adopted in this paper by considering the different car makers who have located their assembling plants and their supply chains in various states in Mexico or that have strategic suppliers in Mexico.

Interviews

Three main issues must be addressed in using qualitative sources of information: criteria adopted for the selection of interviews, topics of interviews, organization of information collected through the interviews.

Criteria adopted for the selection of interviews

Interviews have been conducted with suppliers, experts, business associations of the automotive industry. With the goal of covering a significant range of cases, a snow-ball approach has been adopted in singling out the companies to be interviewed. In each company, people responsible of different roles have been considered as key informants.

Topics of interviews²

To address the analysis of digital transformation within the companies, it is useful to refer to the analytical framework developed by Motohashi (2017) to study the diffusion of big data in manufacturing companies in Japan. First of all, he highlights the main areas of activities: product development, production, sales and after sales services. Since the level of vertical and horizontal integration may differ between firms, the activities undertaken within and outside the company may differ across firms. There are various types of data that are generated within the company,³ such as computer aided design data and simulation data (generated by the development of products) or ordering data (generated in the interaction with the after-sales services and after-product activities). Data are generated also in the relationship with customers (operating data and failure data) and with suppliers (manufacturing process data and procurement goods inspection data).

Flows of information within the company, between the development department and the production activities (or between a company and its product developer), relate specifically to manufacturing and design requirements and the setting of allowable tolerances. Within production activities, information refers to mass production customisation and process improvements. Information flows between production activities and after-sales services or after-product development characterize traceability, which is relevant for improving companies' performance. In particular, prediction of failures and potential cost reduction is associated to the information flows between after-sales activities and the customers. Information on consumable orders fosters a more effective prediction of demand and management of inventories (of both final products and bought raw materials, intermediate goods and components).

All the information flows mentioned above require not only the investment in dedicated machinery, devices and software applications, but also a structure of permissions within and outside the company, to support effective actions. Although this issue is not new in the organisation literature dealing with innovation processes (Lane *et al.*, 1996), it becomes a critical feature to be considered when interpreting the different patterns of adoption of digital technologies within a supply chain. The generation and use of data in each activity and the exchange of data between activities (as in the case of the development department using data collected in the production process) is a critical feature calling for collaboration within companies' departments or between companies (suppliers or customers). The management structure adopted in the use of data, the presence or absence of a specialised department to promote the use of big data, the human resources needed for the use of data in the various departments, may create barriers to the use of data and may reduce the impact of big data on the performance of companies.

Interviews with business companies will target the following topics: (a) the description of the company (history, size, core values, design philosophy); (b) product

² The first three paragraphs of this section are extracted from Russo (2019).

³ The several, diverse flows of information are supported by different software applications, such as Computer Aided Design Manufacturing; Computer Aided Engineering (CAD/CAM, CAE), Simulation, Product Life Cycle Management (PLM); Manufacturing Execution System (MES), Supply Chain Management (SCM); Enterprise Resources Planning (ERP).

and processing specialisations (components & processing), vertical/horizontal integration; products (description, size of batches/series), import content; markets (segments and growth), competitors; (c) technological competences in the relevant domains, according to the specific activities undertaken by the company, and specifically with regard to digitalisation and software skills; (d) relationships with customers, competitors, suppliers, government, other companies, business organisations; (e) innovation, investment, R&D, co-design, future projects; (f) working environment and working conditions will be analysed; (g) industrial and training policies and policies for retaining workforce and cultural factors will be discussed; (h) firms' collaboration within and across-sectors will be explored to single out: cross industry transformations, competence networks in which the companies are embedded, spill over effects and diversification into new sectors and markets (such as: aerospace, electric vehicles, truck, buses); (i) cost and price advantages of local production, vis-à-vis foreign competitors, and impact of the signed and effective trade agreements with the US and Canada; (j) assessment of the impact of the actual conditions of the trade agreement with the US and Canada; (k) the impact of digital transformation in the different specialisations in the production of components and in the relative position of companies in the supply chain (tier 1 vs tier 2, tier 3); (l) strategic location of multi-plant companies in the various states.

A focus on the ongoing digital transformation explores systematically: (m) which technologies are adopted and in relation to which processes/activities/tasks (e.g. Internet of things, big data and data analytics, robots, augmented reality, additive manufacturing); (n) use/ownership of technologies; (o) new actors and competences (software designers for data collection and data analytics), both within and outside the firms.

Organization of information collected through the interviews

Interviews (in Spanish and English) have been recorded and transcribed. To reduce costs and optimizing the quality of the transcription, a preliminary transcription has been obtained by using Speechmatics⁴, a software application to create automatic transcription from audio files. In order to improve the quality of transcriptions, researchers have used the open source application Autoedit⁵ to correct the automatic transcription, also by adding appropriate punctuation⁶.

⁴ www.speechmatics.com

⁵ <https://www.autoedit.io/>

⁶ The audio files were used to test the functionality of new speech-to-text transcription software applications: Speechmatics, IBM Watson, AssemblyAI, Call to an ASR Service. Avasto (2017, ch.2) presents a detailed comparison of various tools and their effectiveness in automatic transcription. She analysed two interviews in which none of the participants were native English speakers and all participants were using "global English. The software misunderstands most of the communication when the concept is poorly formulated, or the microphone suffers a lot of interference. Focusing on the Speechmatics (very easy access and cheaper than other sw), Avasto observes that, for the two interviews she examined, the results of automatic transcription is not satisfactory and the human intervention is necessary because of the following drawbacks: «The division by paragraphs is determined by the speaker's pauses and not by the actual speaking shifts; Punctuation is non-existent; In case of repetitions of the same word by the speaker, Speechmatics understands and creates a new nonsense word; In the presence of another language, different from the one set for the transcription, Speechmatics tries to match words to the English context. Therefore, it does not have the ability to detect and signal the impossibility of a correct transcription due to a different language; Unrecognized acronyms; Names

Data

In January-February 2019, the research team conducted two meetings with business associations (Canacintra, INA) and eight one-to-one interviews to managers of public agencies (AMIA, InnovaUNAM, ITA, JETRO), two experts (respectively, of innovation policy in Mexico and of the economic situation of the country), and eleven managers (in the purchasing, production, R&D, human resources, logistics functions) in tier-1 and tier-2 suppliers, located in Queretaro and in Mexico City⁷.

In this paper we present the results of the interviews to companies, grouped by company.

Expert coding and automatic content analysis

In order to outline a systematic analysis of facts and critical issues emerging from interviews, a combined series of methods is implemented to highlight rich points and outlining an interpretative framework. In particular, a two-step analysis is implemented: expert coding and automatic content analysis.

Expert coding by using Atlas.ti

Expert coding is an iterative process of categorization of contents that are associated to fragments of text, undertaken by reading and annotating transcriptions (Agar, 1996, 2006). By using the Atlas.ti software (Friese, 2016), automatic coding can be very efficient in detecting in a systematic way various entities mentioned in the interviews (such as, acronyms, names of companies, countries, city, inputs, products, technologies). Coding allows annotation of the rationale for each category that has been created, comments on quotations, grouping of categories according to the type of content (such as, all categories associated to the "Company various info", encompassing "Information concerning the companies under examination: description of the company, its history, its staff, core values, product specialisation, contacts with other institutions such as government, universities, but also other companies"⁸), or the specific type of entity. Atlas.ti allows multiple coding by the various researchers and conflicts resolution in the assignment of codes to fragments of texts by the various researchers involved in the analysis. Coding is essentially an iterative procedure supporting the creation of a framework to interpret the contents emerging from the interviews and to share the structure of content analysis among the team's members.

Atlas.ti supports such expert analysis, producing, for each interview, several types of output, including the list of quotations and relative codes, code groups and comments,

from companies or people's surname are not corrected transcribed; The overlapping of several voices makes it impossible to transcribe correctly; "Well" is always perceived as "while"» (Avasto, 2017: 40).

⁷ Interviews have been conducted by Jorge Carreto Sanginés, Margherita Russo, Anna Simonazzi.

⁸ With regard to the present set of interviews, the following codes have been created under the heading "Company various info": agreement with supplier/customers, competitive advantage, core values, description, design philosophy, future project, group, history, inventory management, technological competences; vertical/horizontal integration. The group "Company various info" encompasses, in turn, several other groups of information: of the means of transport (airplane, harbour, last mile, rail/train, truck) and logistic characteristic of the interviewed company; of products characteristics (description, specific automotive component, import content, size of batches/series); target sector (aerospace, automotive industry, electric vehicles, trucks); of the relationships embedding the company in a network (with customers, with government, with other companies, with university, within the group).

reference identification⁹. Atlas.ti is also used by the research team to categorize various pieces of information collected from secondary sources, needed to support in a systematic way a command on information provided by interviews, to create English translations (in the form of comments to quotations, or as free memo).

It should be noted that coding is essential when interviews are multilingual (as in our case study, where we have three interviews in English and one in Italian).

Multidimensional analysis of coding

Each code represents a descriptive information of the topics defined in the quotation. Through a correspondence analysis of a matrix of *Interviews* \times *Codes* it is possible to have a summary representation of the main relationships existing between the interviews and the codes. The resulting factorial plan represents the combinations of a matrix of *Interviews* \times *Codes*. The position of *Codes* on the factorial plan is a function of the association of their occurrences in the *Interviews*, thus expressing their similarity or diversity: two *codes* are close because they are present in the same *Interview*. Through a correspondence analysis (CA), the row and column elements of the matrix are mathematically formalized as vectors, and the above profiles are represented by points in a multidimensional space. The distances between the lexical profiles are measured using a weighted Euclidean metric (chi-square metric). The complex multidimensional space of the variables (codes, in our case) is then reduced to a few key factors that can represent, on dimensions named "factorial axes", the relationships between the elements of the data matrix. CA produces the best simultaneous representation of row profiles vs. column profiles in each factorial plan, and on each of its axes (Bolasco, 2012).

Results

A. An overview from the multidimensional analysis

The empirical analysis provided clues for understanding the multiple changes in technologies and trades in a multilateral perspective. Building on the papers by Carreto Sancinés (2019) and Russo (2019), in this section we summarise the key information and issues emerging from interviews (Figure 4).

The various entities mentioned in the interviews have been grouped in the following categories: companies¹⁰, raw materials (aluminium, plastic, rubber, steel), digital technologies¹¹, other technologies (company inventory management, dies, lamination processes, standardization method, surface treatment), auto components produced by the

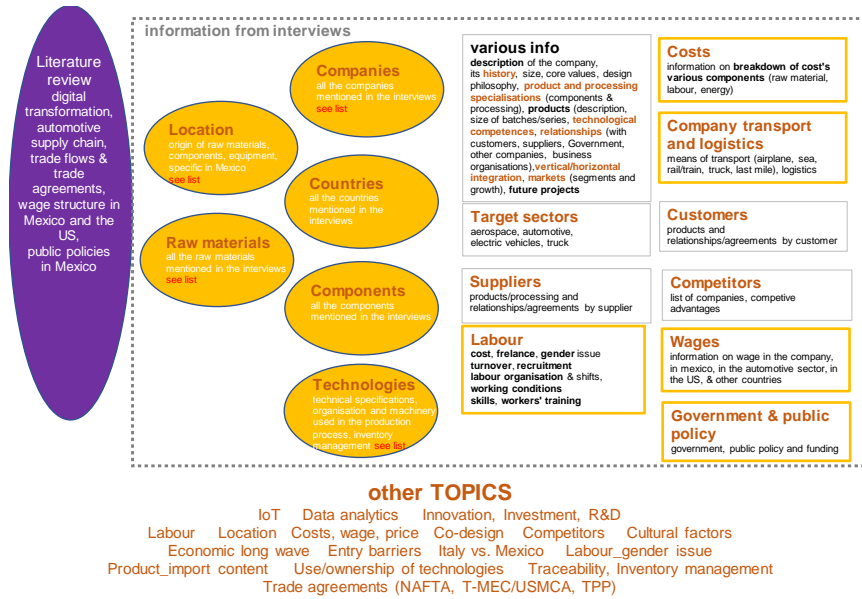
⁹ Reference of the quotation is the interval between word number at the beginning and at the end of the fragment of text associated to each code.

¹⁰ Almexa, Audi, Bitron, BMW, Bombardier, Bosch, Calsonic Kansei, Caltech, Canacintra, Chrysler, Dacia, Daimler, Dark trace, Dina, Faurecia, FCA, Ferrari, Fiat, Ford, General Electric, General Motors, Hedatec, Hirotec, Honda, Isuzu, Magneti Marelli, Mazda, McLaren, Navistar, Nissan, Packard, Parker, Peugeot, Policonductos S.A., Prominox, Renault, Sace, Siemens, Tenneco, Tesla, Toyota, Tradimetal, Umo, Volkswagen, Volvo, Yasaki

¹¹ 3D printing, Artificial intelligence, Augmented reality, autonomous driving, Big Data, CIM (computer-integrated manufacturing), Cloud computing, Data Analysis, EDI, ERP, Industry 4.0, IoT, Machine learning, OPC, PLM, QED, RPA, SAP

interviewed company or mentioned in relation to their production¹², countries or geographical areas¹³.

Figure 4 – Summary of key information and issues emerging from interviews



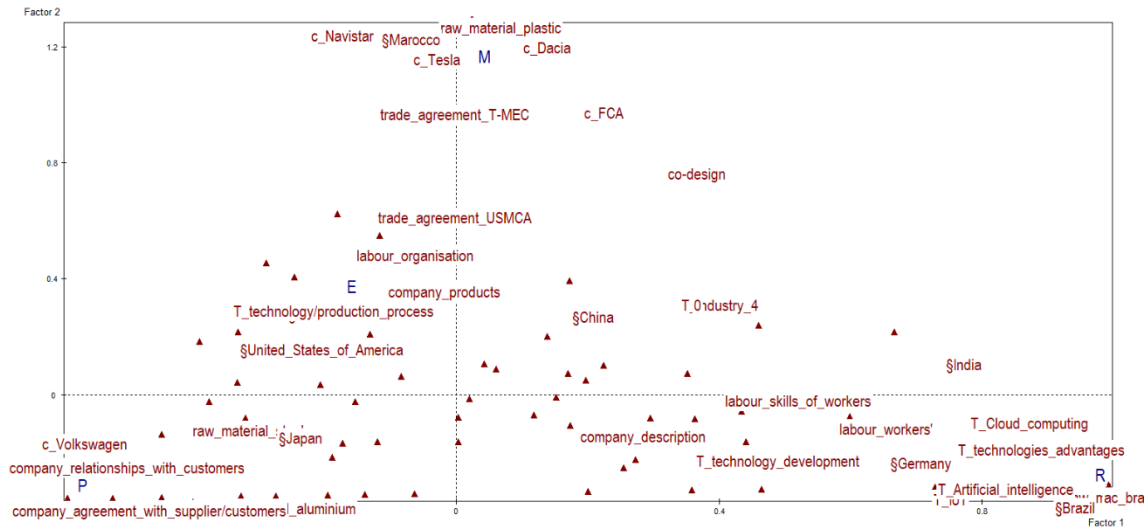
Source: authors' elaboration on interviews

A way to summarize the results of the interviews is through the multidimensional analysis of codes presented in the factorial plan in Figure 5. We observe a polarization along factor 1, which can be interpreted in terms of the relative importance of digital technologies in the production process in the four companies: Company-P (at the left of factor 1) focus the presentation of the company on manufacturing processes using digital technologies, Company-R (at the right of factor 1) describes the digital processes implemented in manufacturing process as a pilot for the other companies in the group Company-R belongs to. With regard to the set of case studies under analysis, factor 2 polarises another main difference among the four companies: the three well established companies in Mexico (P, E, R), at the bottom, versus a start-up, Company-M, that has only very recently started its activity in Mexico.

¹² brackets, brakes, catalytic converters, engine, exhaust system, flanges, fuses, hangers, mufflers, pipes_mechanical, pipes_straight, suspension, terminals, vehicles_components

¹³ Asia, Brazil, California, Canada, China, France, Germany, Germany-Stuttgart, India, Italy, Japan, Japan-Tokyo, Korea, Morocco, Mexico, South Africa, Spain, Taiwan, United States of America.

Figure 5 – Factorial plan f1-f2, correspondence analysis of the matrix *interviews x codes*



Source: authors' elaboration on interviews

For each of the companies, specific codes characterize the topics addressed during the interviews. With regard to the four cases, the analysis of specificity returns the codes that are listed in Annex 1-Table 1 (in increasing order of p-value). The positive specificity of a term measures, from a probabilistic point of view, the over-use of the term with respect to its "expected" value. Such analysis allows a focus on the set of topics that emerge as characterizing each company. For example, in the case of Company-P, a tier-1 supplier of Nissan and Volkswagen, with a recent investment in San Luis Potosí, the core production is that of exhausting systems; dies (design, production, storage, maintenance) are a critical tool for processing operations; relationships among companies in the supply chain is an important feature, with regard both to customers and suppliers (in a context of agreements signed between companies); pivotal raw material is aluminium. From the factorial analysis, Company-R is on the opposite side of factor 1. This interview has focused on company core values, pivotal of the innovation discourse; the core products are suspensions and brakes; the technologies that constitute an advantage for Company-R are an array of digital technologies (Machine_learning, RPA, IoT, Artificial_intelligence, Cloud_computing); critical issues are training, and the labour force conditions (issue of how retaining workers trained by the company, the need to engage young people); pivotal raw material is rubber; tier-1 supplier of BMW (and Germany is a reference country in that context). Interview to Company-E presents many topics dealt by the other companies (and this explains its central position in the factorial plan), but a specificity on the core technology of lamination of steel, with a unique reference to Siemens (provider of the digital devices to implement the digital twin) and a customer located in California; in this case, competitors appear a critical issue. Lastly, Company-M, for which Mexico is the country of its recent location: the trade agreements (in the double denomination of USMCA, from the US perspective, and T-MEC, from the Mexican perspective) constitute an open issue for the future of Company-M; plastic is the pivotal raw material of this case study (main component of fuses produced by the company); an array of companies is mentioned as suppliers and customers (FCA,

Navistar, Sace, Yasaki, Tesla, Dacia); Morocco is the corresponding country for the complementary components.

B. Qualitative analysis

Impact of the new trade agreement with US and Canada

Feedback from interviews show positive expectations of the impact of the new agreement on the Mexican automotive industry, though the ultimate assessment will depend on the final decisions to be made with respect to the four rules to be fulfilled in the USMCA/T-MEC: the share of regional value content (RVC), the share of purchases of steel and aluminium in the region, the minimum per hour wage, the RVC of the core auto parts.

With regard to regional content, its effects inside the country and its cross-country impact on the global value chain will depend on the rules that will be eventually defined: while two of the rules (those requiring a minimum regional content) are likely to benefit Mexico, the overall effect will depend on the definition of the penalties for non-compliance and on the strategies of the OEMs relative to their suppliers' present location.

Interviews highlight that there is a change in the geographical advantages of different location of global value chains, as well as a migration of value along these chains: Mexican suppliers of components are playing a bridging role between the new demand, driven by Industry 4.0 adopted by the customers, and the changing geography of production, driven both by the geopolitical changes, which are at the core of the US and China conflicts/alliances, and the emerging new competences as distinctive of some countries (such as, special steel production in South Korea, or China). Both Mexican and foreign companies are expanding their productive capacity in Mexico¹⁴ and the location of new plants is driven by the incentives offered by the states, which try to attract plants with high value added technologies/products.

Digital Transformation

Compounded with revision of trade policies and geo-political alterations, digitalisation is producing changes in the architecture of productive chains, with relevant competence networks extending over different dimensions: from within the country to across the region (US, Canada) and the global value chains (e.g. Japan, China, Italy). Digital transformation is causing a significant disruption in the strategies of the diverse actors involved. Change creates threats as well as opportunities for the car makers to keep segments of their value chains in Mexico, where suppliers of components play a critical role for the development of new cars (such as the electrical vehicles), and in the production of small batches needed for special vehicles.

Technology is changing the way things are being produced and the way firms conduct innovation activities; this often leads to organisational changes within firms, but also to changes in patterns of interaction and collaboration with other actors in the innovation ecosystems (within the country but also in the global value chain). Digitalisation of productive processes and services - robotization, IoT and the overall components of

¹⁴ The reduction of production and employment in Nissan is due to a reorganization needed to cope with changes in the upsurge of demand for different cars in the US.

Industry 4.0 - is already producing several changes upon the value chain of the automotive industry in Mexico, as emerging from interviews.

Heterogeneity, cross industry transformation and competence networks

A range of digital technologies has been adopted and, though not coinciding simply with robotization or full integration among various stages of the production process, it has already produced significant effects on cost reduction and on the emergence of new actors and competences (among others, software designers for data collection and data analytics) both within and outside the firm, cross industry transformations (with impacts on automotive, aerospace, truck and buses). Relevant competence networks span within the country, across the region (US, Canada) and the global value chains (e.g. Japan, China, Italy).

Between digital and manual: the digital representation of the production process

In the companies interviewed, the focus of the digital transformation concerns the digital representation of the production process. The production process is automated, but the machines are fed and unloaded mainly manually. The movement of loads (beyond the limits set by the standards) is assisted by bridge cranes or pneumatic devices. The repetitive work on board the machine may not be exhausting, but it is continuous (the only breaks are for lunch). Digital technology consists of digital controls of the operation of individual machines (forging, stamping, etc.). It allows suppliers (but also workers) to be aligned with the customers' needs (tier-1 and OEMs) in keeping track of the production, and in the optimisation and control of the production process.

Automation and manual work

The automation of the moulding and forming phases (with high power, capacity and precision plants) is flanked by manual operations to unload the machined pieces, but also to fix welding nuts. The welding of pipes and sub-assemblies (mufflers, for example) is still a highly professional operation, carried out by hand, due to the small size of the batches produced. Relative small size of batches and relative low volume of production still find in manual tasks a source of flexibility to reduce average costs.

Software skills

The development of software applications for data collection, transmission and processing is based on a constellation of specific applications, some developed ad hoc by freelance consultants, other purchased from digital start-ups. The overall home-made design did not seem different from what we found in companies that make use of Siemens platform. The emergence of new forms of labour, new actors and competences (e.g., software designers for data collection and data analytics), both within and outside the firm, requires the adoption of a more appropriate unit of analysis to tackle the ongoing industrial transformation, beyond the individual company or groups of companies with the same classification of economic activity

Digital transformation: a marketing issue

Digital transformation is addressed by some companies as a marketing issue: a leverage to broaden their possibilities as suppliers in developing markets, such as the aerospace industry. This perspective might be specific of some specializations in the supply chain and not simply generalizable to all the specializations.

Working conditions: environment, gender issues and socio-cultural factors

Compared to the standards of similar Italian companies, the requirements for air quality in the shop floor seem less stringent (although they have the environmental certification Iso14001). It is the rhythm of workday, without breaks (4 hours plus another 4 after a lunch break of one hour) that makes the difference.

The presence of very young women (under 30) in the role of managers (in the areas of human resources management and in test and control management) appears to be a positive factor, in a society where the level of education is increasing and where women have competences and determination.

However, it clearly emerged from the interviews that women still cannot exploit their potential of change when, in the lower level occupations, they are marginalized after maternity: being often single, they cannot afford the child care. Although companies, increasingly well located in very modern and efficient industrial parks, provide bus transport for their employees, distances may be too far to become viable to a mother - single with kids – with a burden of 8 hour/day of work, plus one hour of pause, and 4 hours for commuting. In such contexts, social policies are strongly required to allow effective opportunities for women. Moreover, given the states' policies to attract high-value added production in industrial poles, social policies (providing services from kindergartens to health) are also needed to give workers the possibility to live with their family in the surroundings.

Experiences inspired to dual training and lifelong learning are targeting a critical issue for the companies: retaining workers that have been trained and have acquired relevant skills to support the growth of the company. Such experiences have also an expected impact on families and local communities, aiming at supporting the enhancement of learning and education in the population.

Policy implications and further development

This preliminary analysis has provided the research team with a methodological test for further empirical analysis: the outline of topics to be addressed in the interviews, the setting of the interview (separate interviews to each of the managers and/or an opportunity for a collective dialogue on the research issues); but also the methods to be adopted in organizing the various materials collected through the interviews (recordings, notes, transcriptions) and the analysis of contents (expert coding and multidimensional analysis).

Moreover, it has raised a set of research questions concerning the adoption/diffusion of innovations and the policy implications of change.

First, in three of the interviewed companies, research and innovation is considered a strategic asset for their development. This suggests to explore in greater detail the conditions that favoured this mind-set, in a country that is generally studied for its low

wage advantage and the maquiladoras operating as dependent subcontractor of US companies.

Second, in the overall design shaping the global value chain in the automotive industry, there are opportunities for the OEMs to keep important segments of their value chains in Mexico. This preliminary conclusion has policy implications for the Federal and the State governments in Mexico, concerning industrial and social policies. Managers, interviewed both in the company and in the meetings with business associations, have pointed out a detailed list of industrial, research and training policies to accelerate the pace of change, with a focus on young people as carriers of new knowledge. The Government is called for systemic policies (transport infrastructure, for example, or the fight against corruption, on which this government has embarked), besides industrial and training policies and policies for retaining workforce. These preliminary findings show the importance of understanding the multiple changes in technologies and trade in a multilateral perspective as well as the key role that public policy must play.

Building on our preliminary work, further developments of the research will focus on tier-1 and tier-2 suppliers in the main segments of the automotive supply chain and on their customers. In particular, we will consider tier-1 suppliers with the same specialisations of the tier-2 suppliers already interviewed, and their OEMs. We will consider the different car makers who have located their assembling plants and their supply chains in various states in Mexico.

Interviews with digital service producers will allow investigating qualified skills availability and spill-over effects.

Interviews with government officials and stakeholders will be organized in order to discuss the opportunities and constraints of policy programmes and measures on commercial policy, regional and industrial policy and funding; issues of multilevel coordination, future programs. Such analysis will be complemented by a desk analysis of official documents, aiming at providing an overall framework in which to interpret the results from interviews with a focus on policy indications for the federal and the state governments in Mexico.

A further method that might be implemented to summarize large multidimensional analysis of coding is cluster analysis on the of the many categories associated to fragments of the interviews under analysis.

A complementary analysis will be undertaken in order to collect and analyse, in a comparative perspective, the various policy measures adopted by the states in Mexico, with regard to the array of measure implemented to attract investments, support training of workers, provide industrial infrastructure, supply social services and welfare conditions to attract workers for the industry and related services.

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Annex 1 - Table 1 – Specific codes

case study	Characteristic Codes	p-value	case study	Characteristic Codes	p-value
company E	T_lamination_process	7.3E-05	company P	c_Nissan	6.4E-08
	raw_material_steel	1.6E-04		location_San_Luis_Potosi	2.9E-05
	c_Siemens	4.9E-04		c_Volkswagen	2.0E-04
	T_technology_testing	1.3E-02		ac_exhaust_system	4.0E-04
	competitors	1.7E-02		T_dies	4.0E-04
	§California	2.2E-02		supply_chain	1.2E-03
T_Big_Data	2.2E-02	company_relationships_with_customers	1.5E-03		
company M	§Mexico	2.6E-03	c_Calsonic_Kansei	2.3E-03	
	company_products	2.5E-03	c_Magneti_Marelli	5.5E-03	
	trade_agreement_USMCA	9.6E-03	company_agreement_with_supplier/customers	1.3E-02	
	ac_fuses	4.4E-09	raw_material_aluminium	1.8E-02	
	labour_organisation	2.1E-02	platform	5.2E-08	
	trade_agreement_T-MEC	5.9E-03	company_core_values	2.6E-06	
	c_FCA	2.3E-03	T_technologies_advantages	3.2E-06	
	raw_material_plastic	3.3E-03	innovation_discourse	3.5E-05	
	c_Navistar	2.2E-02	T_Machine_learning	3.5E-05	
	c_Sace	2.2E-02	ac_suspension	1.7E-03	
	c_Yasaki	2.2E-02	T_RPA	1.7E-03	
	c_Tesla	2.2E-02	_training	2.3E-03	
	§Marocco	2.2E-02	labour_workers'	2.3E-03	
	c_Dacia	2.2E-02	company_description	6.0E-03	
			§Germany	8.3E-03	
			T_IoT	8.3E-03	
		raw_material_rubber	2.2E-02		
		c_BMW	2.2E-02		
		ac_brakes	2.2E-02		
		T_Artificial_intelligence	2.2E-02		
		T_Cloud_computing	2.2E-02		

Source: Authors' elaboration from interviews