

# **Digital Transformation of the Italian and US Automotive Supply Chains: Evidence from Survey Data**

Ruggero Colombari (Politecnico di Torino)

Aldo Geuna (Università di Torino)

Susan Helper (Case Western Reserve University)

Raphael Martins (New York University)

Emilio Paolucci (Politecnico di Torino)

Riccardo Ricci (Politecnico di Torino)

Robert Seamans (New York University)

## **Abstract**

We provide results from a detailed survey of automation and digitization in firms in the automotive sectors in the United States and Italy. In both countries, we find evidence of heterogeneity of organizational architectures—some firms organize around a “Taylorist” approach and others around a pragmatic approach. We find some notable differences in the adoption and use of new technologies, particularly robots. In the US, robots are considered an effective tool to address skill shortage, but not as much in Italy. This is partly explained by the fact that in the US finding workers who possess the desired skills is seen as a major challenge. Italian firms attribute to robots a higher impact on improving safety conditions in the shop floor. This might explain why Italian firms have adopted more technologies for parts tracking, given they are frequently used to trace all the production processes to guarantee product safety. Overall, firms in both countries appear more likely to adopt robots to increase quality rather than to reduce unit and labor costs. Despite technology adoption is underway (though more in the US), we found that companies in both countries (especially in US) are not automating data collection suggesting that firms are not utilizing the new automation and digitization technologies to their fullest extent but in the “old” way.

## 1. Introduction

Recent advances in technologies for data collection (e.g. sensors, parts tracking, machine vision) and analysis (e.g. algorithms and artificial intelligence) applied to robotics and other automation technologies are leading to many innovations, including autonomous vehicles and smart manufacturing (CEA, 2016). In manufacturing, the combination of these technologies might involve using sensors on robotics and other equipment to engage in the continuous collection of data in real-time, the storage of this data in a central location, and the use of sophisticated software tools to analyze this data and predict performance (Agrawal, Gans and Goldfarb, 2018). The revolutionary potential of these new technologies for manufacturing and labor productivity has led to the emergence of a new technological paradigm named "Industry 4.0" (Kagermann et al., 2013; Oesterreich and Teuteberg, 2016) and "digital supply chain" (Benitez et al., 2020). However, it is unclear how these technologies will affect the workforce, and how the role of institutional differences will affect the deployment of these new technologies across countries.

Despite the large availability of technologies, some even under open source approaches (Kahle et al., 2020), managers face difficulty in understanding how to implement the technologies in their organizations (Zheng et al., 2019). Other than technological and environmental factors, scholars largely agree that new technologies, such as Industry 4.0, are most effective in improving firm performance if they are accompanied by changes in organizational structure and incentives, through the implementation of a set of managerial and organizational practices such as flat organizational structures and empowerment of production workers (e.g. Brynjolfsson and Hitt, 2000; Cagliano et al., 2019; Cimini et al., 2020; Gillani et al., 2020). Others argue that Industry 4.0 technologies enable improved performance through centralization of decision rights (Aboagye et al., 2017).

In this paper, we propose that the adoption and use of technologies will likely differ according to managerial and political choices (Helper et al., 2019, Cetrulo and Nuvolari, 2019). In some cases, adoption of technology can be relatively straightforward, particularly if the technology is a separable input that does not involve interactions with other inputs into a firm's production function. In other cases, it can be complex, as when there are complementarities, for example between the new technology, labor, and incentive structure (Bresnahan, Brynjolfsson, and Hitt 2002; Brynjolfsson and Milgrom 2013). In this respect, firms may differ from each other in systematic ways, with some firms preferring to organize around separable production inputs and others around complementary production inputs. We refer to the difference between these two as the "organizational architecture" of the firm, proposing that they may have different implications on how firms adopt and use new technologies. In this paper, we focus in particular on the use of robots, given that it is the main operational technology in the shop floor that will be integrated with digitization technologies.

The adoption of Industry 4.0 technologies has been surveyed only in single countries as in Brazil (Tortorella and Fetterman, 2017) and Italy (Zheng et al., 2019). There are few cross-country studies (Gillani et al., 2020) that can control for the specificities of the country such as national culture and institutional factors taking as fixed the industry type. Indeed, the experience in one country may differ dramatically from that in another country, depending on variance in different institutional structures across countries. In the past, for example, Japanese, German, and American firms have adopted automation in different ways. For instance, in adopting computerized machine tools (CNC) German firms were more likely to combine the functions of programmer and machine operator, while American firms have typically separated them (Kelley, 1994; Noble, 1978)

To fill these gaps, we conduct detailed surveys of plants in the automotive supply chain for two countries: the United States and Italy. We use the survey responses to address the following research questions:

1. What are the level and the intensity of adoption of automation and digitization technologies in the automotive industry in two major industrialized nations: US and Italy?
2. Do automotive firms differ systematically in terms of organizational architecture? Are there any differences between US and Italy?

3. Do firms differ regarding the use and impact of robots? Are there any differences between US and Italy? Is their impact determined by the organizational architecture?

Provided that there are differences in incentives and in size, we found that how such technologies are adopted is complementary to organizational structures. The paper follows this structure. First, we provide prior literature on how digital manufacturing and organizational architectures are adopted in the automobile industry. In section 3, we depict the US and the Italian automobile contexts, again with a focus on Industry 4.0 and high-involvement organizational practices. In section 4 we explain in detail our data and how we collected it and built our measures. Then we show our findings, in three sections related to our RQs and a fourth to show the relationships with the supply chain. Following, we show the preliminary results of our regressions and discuss them to conclude.

## **2. Prior Literature**

### **2.1. The automotive industry and digital manufacturing**

Digital Manufacturing or Industry 4.0 refers to the increasing trend of automation and digitization of the manufacturing industries (Oesterreich and Teuteberg, 2016), that is the convergence of operational and information technologies in the manufacturing environment (Agarwal and Brem, 2015). While many of the automation technologies have been in existence for years (robots were first used in the US in the 1960s), recent advances in digitization and enabling technologies - such as hardware miniaturization, efficient batteries, open and standard communication protocols (e.g. MT Connect, MQTT), algorithms for data storage and processing (e.g. Hadoop, NoSQL) and algorithm advancement in the field of Artificial Intelligence (e.g. machine learning) - have in turn enabled connectivity, real-time data collection and predictive analytics.

While much of manufacturing is undergoing a digital transformation, we focus our attention on the automotive industry for several reasons. First, it is known as an early adopter of new technologies. Second, the automotive industry is (among) the most intensive adopters of robots (IFR, 2018). Third, both Italy and the US have strong domestic auto sectors, making comparison meaningful.

The literature on the digital transformation of the automotive industry has largely focused on consumer-facing technologies, such as autonomous vehicles, connected cars and digital servitization (Rachinger et al., 2019) while an investigation of the diffusion of automation and digitization technologies in the shop floor as well their impact on work organization is largely missing.

Exceptions are Corò and Volpe (2020) and Zirpoli and Cabigiosu (2018) who investigate the adoption of technologies respectively in Veneto (a North-East region of Italy) and Italy. Corò and Volpe (2015) confirmed that robotics is the most adopted technology in the automotive industry among other technologies and found a cluster of contemporaneous adopted technologies composed of Robots, sensorized and connected machines (IoT) and Big Data technologies. Indeed, Italy is the second-largest robotic market in Europe after Germany and the seventh in the world. In Italy, the automotive sector is the most important sector accounting for 25% of industrial robot shipments followed by metal products (non-automotive) with 14%. In term of stock, automotive accounts for 32% (Estolatan et al. 2018). In US about half of robot, shipments are to the automotive sector, and about 20 percent to the consumer electronics sector (Furman and Seamans, 2018). Automotive purchasers account for 39% of the stock of robots in the US, by far the largest sector (Acemoglu and Restrepo, 2017). In autos there were approximately 1,091 robots per 10,000 workers in 2012. In contrast, the average of all other industries was 76 robots per 10,000 workers (CEA, 2016). In sum, these data suggest that the automotive industries in the US and Italy are approaching the Industry 4.0 paradigm faster than other industries.

Despite being front-runners with respect to other industries, some studies document a limited adoption of both automation and digitization technologies in absolute value in the Italian auto supply chain even though greater than the population of Italian manufacturing firms (MISE, 2017, Zirpoli and Cabigiosu, 2018). Accordingly, scholars have been interested in analyzing the antecedents of digital manufacturing technologies adoption (Gillani et al., 2020). Corò and Volpe (2015) and another study by Lin et al., (2018) document that company size is not determinant for greater technology adoption level in the automotive industry. However, other studies not tied to the automotive industry document that adoption levels in large enterprises are greater than the small and medium-sized enterprises (Horváth and Szabó, 2019, MISE, 2017). Despite company size being important for the adoption of smart technologies due to greater investment opportunities (Bosman et al., 2019), scholars agree that organizational factors other than contingency factors determine greater adoption levels, including decentralized and flat organizational structures, production workers' autonomy, involvement in problem-solving activities and social interactions (Cagliano et al., 2019, Arcidiacono et al., 2019, Cimini et al., 2020). These organizational practices are often undertaken under the scope of lean management programs (Cimini et al., 2020).

However, such studies implicitly assumed that the organizational architecture is shaped by technology and as such firms should fit their organization under lean management approaches to achieve higher performance. As illustrated by Helper et al, (2019), we argue that organizational architecture may be shaped by firm strategy other than technology and thus could play a role in shaping technology adoption and use.

## **2.2 The automobile industry and organizational architectures**

Following the literature summarized in Helper, Martins, Seamans (2019), we distinguish two broad "organizational architectures". For "Taylorist" firms, workers and technology are substitutes; such firms maintain a strict division of labor both between the "hand work" of transforming materials and the "brain work" of planning and problem-solving. "Pragmatist" firms in contrast value experimentation and believe that front-line workers have the expertise that no one else has. Technology can complement these workers' skills, by improving their access to data and time to engage in problem-solving. Rather than separate planning and execution, the pragmatist view is that workers' knowledge can contribute to innovation and future production, as well as today's operations. Response to problems or opportunities for improvement means that interfaces between tasks are frequently redrawn, so narrow specialization is not useful (Helper, MacDuffie, Sabel, 2000). In this view, technology should serve the worker's ability to improve the process. Humans have much broader sensory capabilities than machines do, so people can give a much richer picture of what is occurring. Too much automation removes this knowledge – Toyota in 2014 actually removed some robots from its factories for this reason.

Much of the knowledge useful for improving production is therefore tacit, at least initially. Once people realize that a certain sound or indicator is important, this knowledge can be codified—standardized work instructions can be written to lay out in detail the best technique for doing a process step, and failure modes delineated. But this step of codification sets in motion another round of efforts to improve on the new standard, and tacit knowledge and a variety of perspectives are again important (Helper et al, 2000; Adler and Borys, 1996). That is, manufacturing, especially in the pragmatist paradigm, does not involve a worker pushing the same button on a machine every 20 seconds for 20 years. Rather, change is daily or weekly, as new products come in and new methods are invented. In the Pragmatist view, this process is most effective if the people doing the work are involved in the standardization because they know the details in a way that an observer, no matter how well-trained, cannot.

These different organizational architectures have significant implications for a variety of aspects of the firm, including operations strategies, technology, worker skills, and compensation (Bresnahan, Brynjolfsson, and Hitt 2002; Brynjolfsson and Milgrom 2013).

### 3. Setting: The US and Italian auto sectors

#### 3.1 The US auto sector

There are several types of players in the US auto industry. The automakers (e.g., Ford, Toyota, Volkswagen) design, market, and assemble cars. They preside over a supply chain that includes large "first-tier" suppliers (suppliers who supply directly to automakers), who are in turn supplied by smaller second-tier suppliers, who are supplied by third-tier suppliers, etc. Automakers capture 70-80 percent of the market capitalization in the industry (Jacobides *et al*, 2016), though this figure overstates their share since many small suppliers are privately held. About 1.5 million people are employed in the US auto parts sector, about four times as many as are employed directly by automakers (Helper, Miller and Muro, 2018)<sup>1</sup>

Automakers rely on a common set of suppliers, which is beneficial in that suppliers can specialize in narrow areas, such as automotive seating. Each automaker benefits from the reduced fixed costs and increased access to suppliers' experience making similar products for other customers. On the other hand, lead firms have reduced incentive to invest in upgrading the supplier's capabilities if that supplier may also use those capabilities to serve a competitor.

In the past, automakers used purchasing strategies selected for suppliers with relatively low bargaining power. The US-owned automakers (GM, Ford, Chrysler) used short-term contracts with many suppliers per part, and took complicated functions (e.g. product design and sub-assembly) in-house. In contrast, Japanese-owned automakers (Toyota, Honda) and their suppliers have emphasized more collaborative relationships. In recent years, US-owned automakers have converged a bit toward Japanese practice (Planning Perspectives, 2017). However, a legacy of small, weak suppliers remains, a legacy that complicates adoption of modern automation practices. Helper and Kuan (2017) documented this weakness, including failure to adopt proven managerial techniques. One-third of auto suppliers have fewer than 500 employees, and fewer than half of these small firms have adopted quality circles (in which production employees gather regularly to troubleshoot quality concerns) and only two-thirds of them self-report that they consistently perform preventative maintenance. A quarter of small automotive firms employ no engineers.

#### 3.2. The Italian auto sector

Italy is one of the leading EU countries for the automotive industry, following Germany and France in terms of sales volume. In total, production and services in the Italian automotive supply chain generate a turnover of over \$361 Bn and have 1.2 million employees. Concerning manufacturing, 99% of Italian firms are SMEs, accounting for 73% of employment (Istat, 2017), and auto part suppliers are not an exception, with an average of 75 employees per firm. There are about 2200 auto suppliers in Italy, with about 162.000 people employed in the Italian auto parts production industry, about twice the 96.600 employed directly by automakers (ANFIA, 2018). Concerning turnover, auto suppliers account for about \$82 Bn, three times as much as automakers (\$27 Bn), while value added at factor cost is \$13 Bn, almost doubling automakers (\$7.5 Bn).

For Italian auto suppliers, 35-40% of the turnover comes from FCA, followed by Volkswagen (about 20%), BMW, RNM and Daimler (about 5-10% each), and some other automakers (15-20%). Due to its predominant role in the Italian market, FCA has enough bargaining power to require suppliers to adopt WCM (World Class Manufacturing, the FCA label for Lean Production) practices, investing time and resources in upgrading its

---

<sup>1</sup> <https://www.brookings.edu/blog/the-avenue/2018/07/02/why-undermining-fuel-efficiency-standards-would-harm-the-us-auto-industry/> Because of difficulties in assigning individual factories to industries, employment in auto parts is significantly underestimated; it is probably twice as large as presented in statistics based on the North American Industrial Classification System (NAICS). (Economic Report of the President 2013; Helper 2012).

suppliers' capabilities. To maintain contracts alive, suppliers must guarantee high standards, quantified through regular assessments.

On the technological side, the automotive industry has been evolving in the last years, with technological updating of plants and processes, probably also enabled by an increase in the average size of companies. An important role has been played by the “Piano nazionale Impresa 4.0” (National Plan Enterprise 4.0) also called “Piano Calenda”, name of the Minister of Economic Development who in 2017 introduced a significant investment plan to foster adoption of technologies related to Industry 4.0 after a lot of years of very minimal industrial policy. It entails tools such as “hyper depreciation” or “tax credit for innovation”, aimed at incentivizing investments in enabling technologies, supporting R&D spending, and promoting training paths to develop the necessary competencies. This led, in the first year, to a \$90 Bn increase in spending (MISE, 2018), distributed into machinery and automation solutions (35%), maintenance and installation of machines (18%), electrical and electronic equipment (10%), and other investments (37%). A criticism often levelled at this investment plan is that it is based on technology push, rather than truly needed adoption of technologies. There are evidence of a large number of SMEs that so far invested in such technologies have used such financial aid and have in particular substituting old machinery or retrofitting existing equipment (Perani et al., 2019). While this could have a short-term impact in reduced investment costs, such adoption process may be accompanied by a limited or partial recognition of the long-term benefits ignited by the adoption of Industry 4.0 (Perani et al., 2019).

## 4. Methodology

### 4.1 Data

We conducted a detailed survey of US and Italian auto supply firms in 2018-2019, which built on an earlier (2011) survey wave. We provided separate surveys for plant, sales and HR managers. The survey was carried out with the support of major industrial automotive associations both in Italy and in the US, the survey response rates were 1-2% for 2011 survey resample, and 15-30% for the sample of firms that were part of the automakers' parts suppliers' associations. A fully comparable survey of Italian firms active in the automotive sector started in October 2018 and will end in April 2020. The survey response rates were 4-5% for the survey resample, and 15-20% for the sample of firms affiliated to suppliers' associations. The unit of analysis is the production plant. In this research, we use comparable data of 90 US plants and 99 Italian plants. In the US, a firm is considered “SME” when it has less than 500 employees, while in Italy such definition pertains to firms with less than 250 employees. According to this definition, we have 70% (US) and 83% (Italy) SMEs in our sample (Table 1).

**Table 1. The research sample, by firm size**

	<b>Total plants</b>	<b>&lt;250</b>	<b>251-499</b>	<b>&gt;=500</b>
<b>US</b>	90	38	25	27
<b>IT</b>	99	82	8	9

In line with the population, the average number of employees per analyzed plant is 405 for US firms, and 109 for Italian firms.

### 4.2 Measures

To measure technology adoption, we asked firms to report whether they adopt or not adopt a specific technology as well as the units of adoption for the same. A list of six technologies was included in the survey. The first set of technologies about digitization include machine vision, sensors and technologies for parts

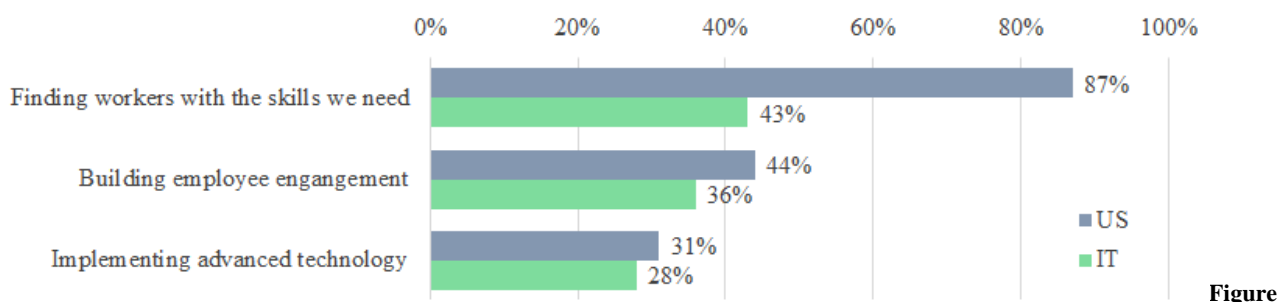
tracking (e.g. bar codes, RFID). The second set of technologies about automation include robots, collaborative robots and Autonomous Guided Vehicles (AGV).

To measure the pragmatism organizational architecture and data-driven decision making we employ novel measures based on the literature reviewed in Helper, Seamans and Martins (2019). The items composing the measures and the results of factor analysis are shown in the appendix. We used the polychoric factor analysis, based on polychoric correlations, which is used when the measure is composed of items with different scales (Zumbo et al., 2007; Eapen and Krishnan, 2019). In fact, in our operationalization the pragmatism and data-driven decision making measures contain both ordinal (binary in our case) and interval scales. The values have been later normalized into a scale where 0 is the minimum and 1 is the maximum. The factor analysis revealed two main dimensions of pragmatism which we confronted and found some similarity in the literature. The former refers to the autonomy given to production workers in managing production equipment including activities such as set-up equipment, modify programs on computerized machines and diagnose equipment problems. The latter refers to the empowerment of production workers in continuous improvement such as using quality data to recommend improvements and make improvements in their methods of operations. We used the regression factor scores to compute the two measures. Through these two dimensions, managers empower production workers to use their contextual knowledge of production processes to manage equipment and bring improvement ideas. We used OLS regressions to investigate the causal relationship between organizational architecture and impacts of robots and the complementarity between production workers and robot on wage. Production workers' wage was measured as hourly salary. We convert Italian Euros into US Dollars using the exchange rate of 1€ = 1.1\$. Impact of robots on KPI such as reducing labor and product unit cost, increasing quality and safety were measured on a five-point Likert Scale. We run separate regression for the two countries to spot similarities and differences. We use as control variables plant size that was measured as the natural logarithm of the plant employment.

## 5. Results

### 5.1 Comparative Descriptive Analysis

To provide a context for our analysis, we asked respondents about the major challenges they faced (US firms were presented with a choice set of seven challenges; Italian firms were presented with a choice set of ten challenges). Firms in the two countries are aligned in identifying the three they are most worried about, shown in Figure 1: (1) Finding workers with appropriate skills, (2) building employee engagement and (3) implementing advanced technology.



1. Main challenges faced by firms, by country

These results are in line with the findings that follow. In the next three sections, we show the differences encountered between the two countries for what concerns the adoption of advanced technology, the organizational architectures (with a focus on employee involvement practices), and impacts of robot adoption, which shows interesting differences across countries on tackling the skill gap.

### 5.1.1 Level and intensity of adoption of automation and digitization technologies

Next, we consider the level and intensity of adoption of various technologies. The US shows a statistically significantly higher number of firms adopting digitization (sensors, machine vision) and automation (robots, cobots, AGVs) technologies (Figure 2).

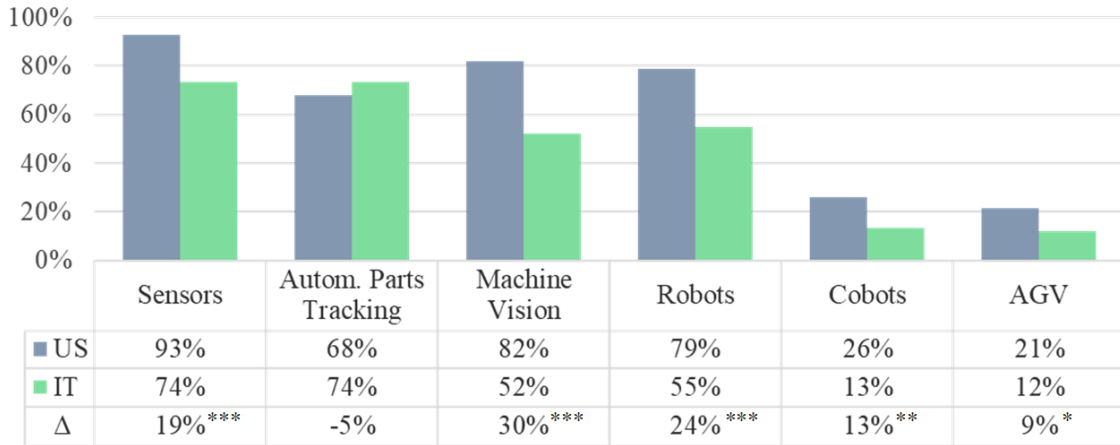


Figure 2. Percentage of firms declaring the adoption of at least one unit of technology

The intensity of such adoption is shown in Figure 3, which reports more in detail the number of machines with sensors, the percentage of parts that are tracked, the number of cameras for machine vision, robot/cobot arms, and AGV units, related to those plants where at least one item of such technology is adopted.

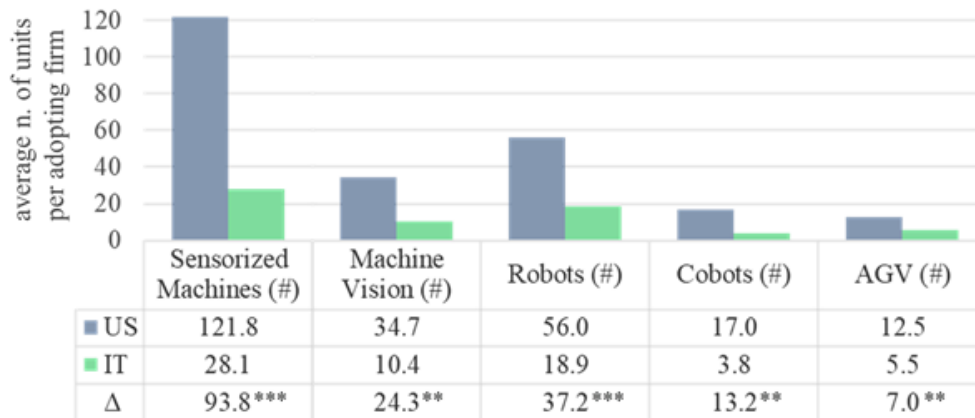
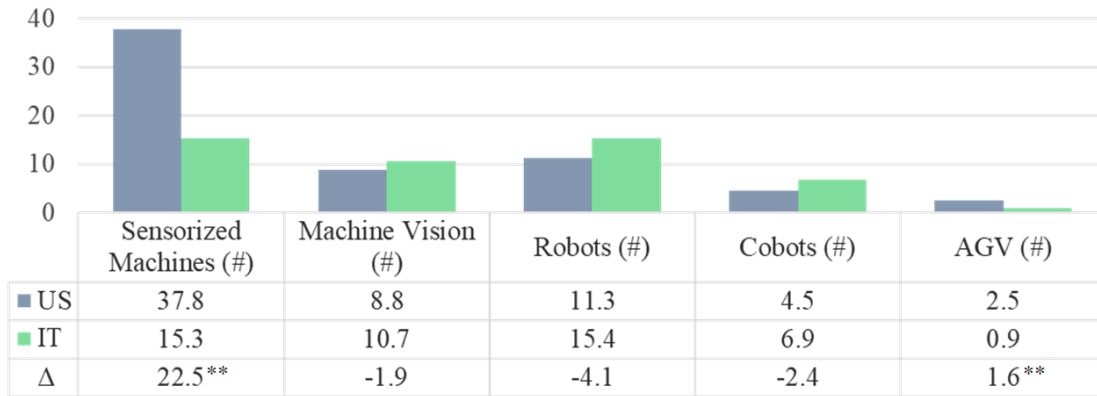


Figure 3. The intensity of technology adoption

Automated parts tracking, which has been measured as a percentage of parts tracked on the total of parts managed, shows a low significant difference (62.7% in the US, 80.5% in Italy). On the other hand, significant differences are found in the number of sensorized machines, robots, cobots, AGVs and cameras for machine vision, for which the US outnumbers Italy. We note that these differences could be driven by plant size differences across the two countries, as US firms are larger than Italian firms, on average. Bigger sizes are associated with higher production volumes, which in turn call for higher need in terms of production equipment such as machinery, robots, AGVs. To moderate such effect, a common practice for what concerns the intensity of technology adoption (e.g. IFR, 2018) is to assess a "density" based on the number of employees. Therefore, in Figure 4 we address this issue by computing the same variables per 100 employees).



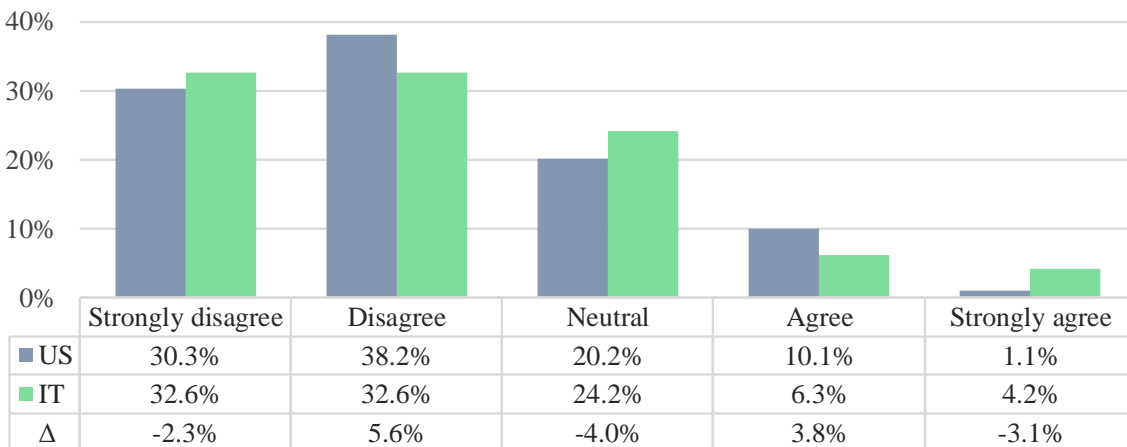


**Figure 4. The intensity of technology adoption, values per 100 employees**

With such adjustments, most of the statistically significant differences disappear, except for sensors and AGVs.

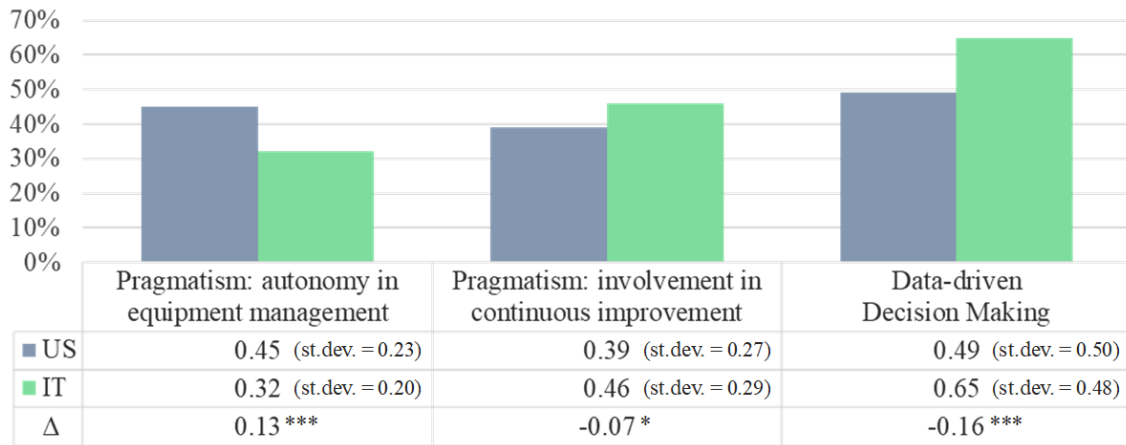
### 5.1.2 Organizational Architectures

Next, we consider the potential for complementarities between new technology and production workers. Figure 5 reports the degree of agreement with the statement “we found that the use of Information Technologies reduces the need for shop-floor workers to have analytical skills”. Few plants list “strongly disagree” or “disagree” with the statement (approximately 11% considering both US and Italy) that agree and strongly agree with such statement thus declaring that the use of IT reduces the need of shop-floor workers analytical skill. The answers suggest that the majority of Italian and US firms are benefitting from their workers’ analytical skills and that the use of information technology is highly complementary. However, a set of neutral and positive (i.e. negative) answers seems to suggest that organizations systematically differ in terms of organizational architecture though with no major difference at the country level for what concerns agreement and disagreement.



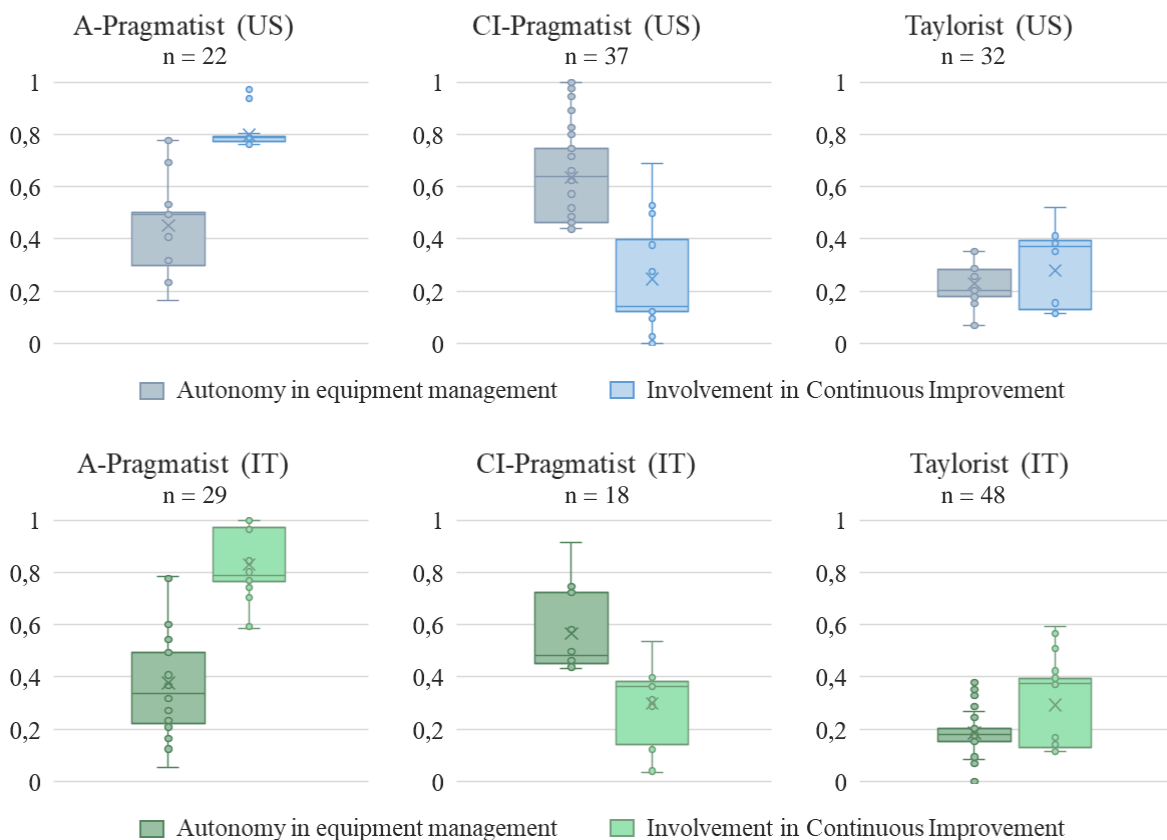
**Figure 5. Degree of agreement on IT reducing the need for analytical skills in production workers**

We next consider how US and Italian firms differ concerning our two measures of Pragmatism and Data-Driven Decision Making. We found a relatively high standard deviation especially for continuous improvement and data-driven decision making. However, the US shows a statistically significant higher measure of pragmatism related to autonomy in equipment management, while Italian firms show a higher propensity to base their decisions on data and involve production workers in continuous improvement processes (Figure 6).



**Figure 6. Measures of Pragmatism and Data-Driven Decision Making**

To further explore these organizational differences across firms, we performed a cluster analysis for the two Pragmatism measures. We found three different clusters with a first group high on autonomy, a second high on continuous improvement and a third with a low level of both pragmatism dimensions, i.e. taylorist (Figure 7). These results support the idea that firms systematically differ in their organizational architecture.



**Figure 7. Clusters of Pragmatists (A: Autonomy, CI: Continuous Improvement) and Taylorists**

Then, we went more in detail concerning the Data-Driven Decision-Making measures. The higher propensity of Italian firms seems to be supported by the way they collect their data. While a large proportion of US firms tend to input data manually, the Italian ones are automatizing the process through sensors and integrated ERP systems (Figure 9).

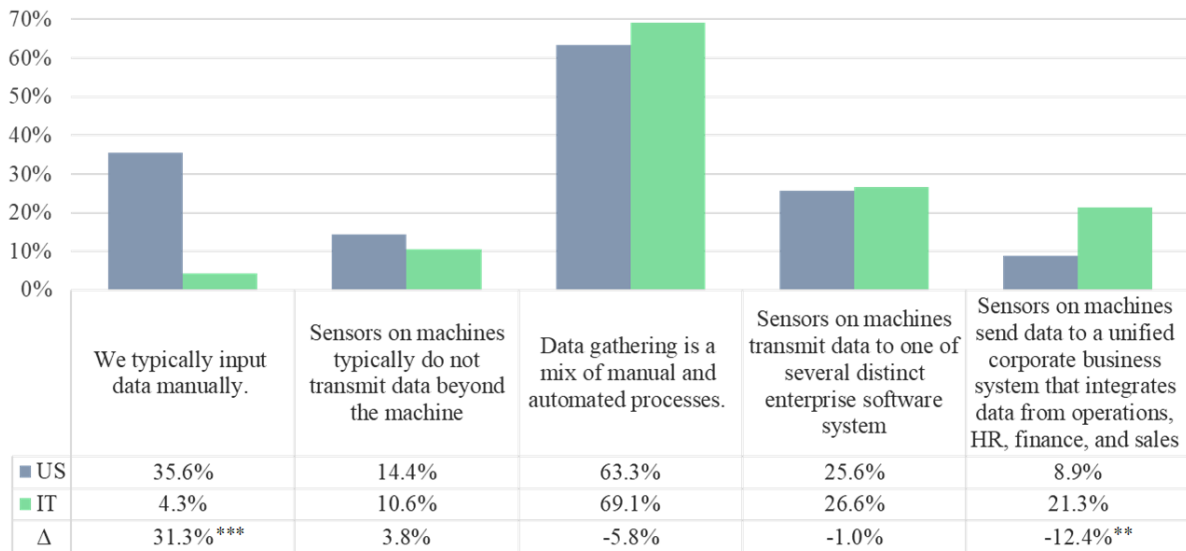


Figure 9. Data collection process: manual vs. automated

### 5.1.3 Use and Impact of Robots

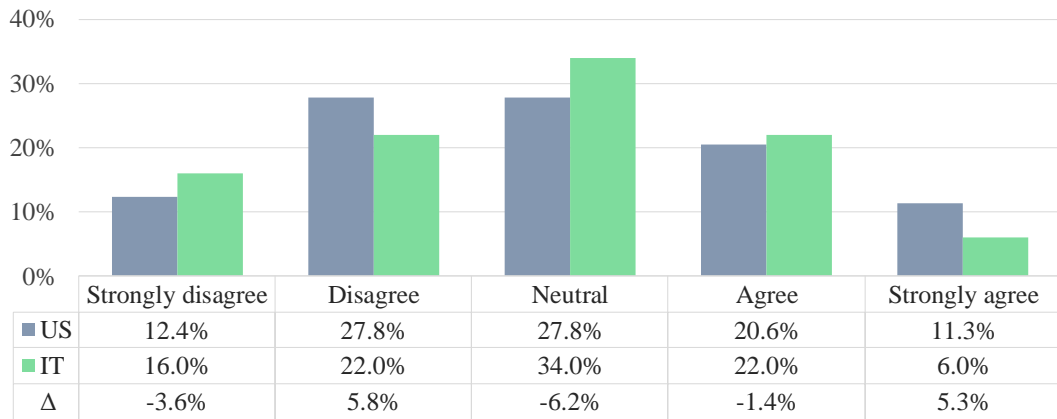
Last, we found significant differences on two out of the nine items we investigated for what concerns the impact and use of robots. In the US, robots appear to have a stronger impact on addressing the skill shortage. In Italy, robots appear to lead to a higher increase in safety (Figure 10). Overall, the increase in quality and safety show interestingly higher values than the reduction of labor and product costs.



Figure 10. Impacts of robots on focal KPIs

### 5.1.4 Relationships with the auto supply chain

Last, we provide information on the relationship with customers and supplier, in particular system integrators. Concerning customer relationships, we investigated the level of collaborative problem-solving amongst companies by asking firms to which extent they agree with the following statement: “We feel that our customer often uses the information we provide to check up on us rather than to solve problems.”. Results, shown in Figure 11, are lightly skewed towards disagreement and neutral opinions. Therefore, negative impressions regarding collaboration represent a minority of answers, though not so irrelevant getting approximately 30% in both countries. No significant differences were found in terms of agreement and disagreement between the two countries.



**Figure 11. Perceptions about a negative relationship with customers on collaborative problem-solving**

On the supplier side, we focused on Industry 4.0 technology suppliers, namely the system integrators. Interestingly, the percentage of firms confirming a collaboration with such player is very similar: 42.6% in the US and 44.3% in Italy.

## 5.2 Preliminary Comparative Econometric Analysis

Preliminary econometric analyses showed that the pragmatism and data-driven decision making do not determine the adoption of technologies. This occurs for both Italy and US. Thus, it seems that the adoption of technologies is unrelated to organizational variables for both countries. By contrast, the use of a system integrator has been always found significant for the adoption of almost all the technologies controlling for plant size. Again, this holds for both US and Italy. Overall, the plant size is found highly significant for the adoption of all the technologies. The same results hold for the intensity of adoption where the organizational variables have not been found significant.

Focusing on robotics, we found that pragmatist architecture does not determine an impact of robot on labor cost reduction or total product unit cost, but it does so on quality though with different direction according to the country. In fact, we found that autonomy to production workers (one of the dimensions of pragmatism) determines a positive and significant relationship with robot increasing quality in US. By contrast, we found a negative and significant relationship between continuous improvement and robot increasing quality in Italy which show that robots are not complementary with production workers continuous improvement initiatives.

**Table 2. Relationship between organizational variables and the impact of robots**

Outcomes \ Regressors	Reduce Labor Cost		Reduce Total Unit Cost		Increase Quality		Increase Safety	
	US	Italy	US	Italy	US	Italy	US	Italy
Data-Driven Decision Making	.200	.099	.219	-1.07	-.791	1.275	-.218	2.05
Production Workers' Autonomy in Equipment Management	.684	-.330	-.297	-1.22	3.04**	-.041	-.926	1.25
Production Workers' Continuous Improvement	-.593	-.075	.085	.784	.412	-2.35*	-.240	-.768
System Integrator	-.129	-.459	-.167	-.532	.930	.498	.181	.451
Ln Employment	.080	-.112	.020	.018	-.032	-.373	.329	-.368
Observations	65	43	63	40	69	44	68	44
R-Squared	0.101	0.056	0.048	0.165	0.177	0.087	0.024	0.050

Last, Table 3 shows that three interesting results for what concern the combined effects of robots and pragmatism on production workers wage. First, we found the combined management' assignment of autonomy to production workers and adoption of robot increases production workers wage in US. Second, we found that the autonomy conditional to non-adoption of robot reduces wages but under the same conditions continuous improvement increases wages in US. Third, we found that adoption of robots' conditional to non-adoption of pragmatism measures determines a reduction of wages in US. We did not find any significant results for Italian data which could probably be determined by the fact the production workers wage in Italy is subject to fixed contracting at a national level between employers and employees' associations.

**Table 3. Complementarity of organizational variables and robots on production workers' wage**

<b>Outcomes</b> <b>Regressors</b>	<b>Production</b> <b>Workers' Wage</b>	<b>Production</b> <b>Workers' Wage</b>
	<i>US</i>	<i>Italy</i>
Autonomy	-8.18**	1.85
Continuous Improvement	4.87*	.308
Robot per Worker	-45.4**	1.38
Autonomy * Robot per Worker	77.8*	-4.52
Continuous Improvement * Robot per Worker	-4.81	-2.08
Ln Employment	.447	.019
Unionized Employees	2.42*	-.588
Multi Plant	-1.06	-.099
Observations	26	72
R-Squared	0.615	0.0752

## 6. Discussion and Conclusion

This paper has compared the US and Italian automotive supply chain regarding the adoption and intensity level of digitization and automation technologies, the existence of different organizational architecture, the impact of robots and some preliminary considerations on the impact of organizational architecture on robots' impact and production workers' wage.

With respect to technologies adoption, we found that digitization technologies (i.e. sensors, automated parts tracking, machine vision) are more frequently adopted than automation technologies (i.e. robot, cobot, AGV) probably due to the different cost of these technologies. With respect to country comparison, on average there are more US firms that have adopted both digitization and automation technologies with the only exception of automated parts tracking. Similar results can be found on the intensity of adoption (i.e. on the number of technologies adopted) due to the greater size of US firms. After controlling for employment, the difference in the intensity of adoption between US and Italy for almost all the technologies is no more significant but dependent on firms' size. This clearly illustrates that size in the adoption of digitization and automation technologies (Bosman et al., 2019; Horváth and Szabó, 2019) and the structural weaknesses of Italian firms characterized by several micro and small and medium-sized enterprises.

Despite digitization is adopted more than automation technologies, we found that companies are not automating data collection. This may suggest that companies are not utilizing the new equipment and digitization technologies to their fullest extent. However, we found that Italian firms seem to be better positioned with respect to U.S. with more automated and integrated data collection and less manually input data. The results seem to suggest the higher propensity of Italian firms to make decision-based on data probably due to higher availability and quality of data.

The fact that US firms are more technology-intensive than Italian firms seem to explain why US firms empower their production workers with more autonomy in equipment management. By contrast, Italian firms rely more on their employees to bring continuous improvement initiatives and less on technology-driven initiatives. This is probably since, apart from the size, Italian firms with low-volume high-mixed productions<sup>2</sup> have not yet identified viable means to use new technologies to achieve the flexibility required by the automotive market but they prefer to rely on their employees.

Overall, we found that firms differ in organizational architectures regardless of country, and this may have an impact on both adoption and use of technologies. In fact, we found a set of firms both in Italy and US that neither empower their production workers in autonomy neither in continuous improvements. This set of plants might share the principles of Taylorism. However, the majority of plants benefits from the skills of production workers even though we found that US plants assign more autonomy to their production workers while Italian plants value continuous improvement.

The results on robot impacts point out two main differences between the two countries. In the US, robots are considered an effective tool to address the skill shortage, whereas Italian firms found skills adjustment to be the area for which robots are less useful. This is partly explained by the fact that, in the US, finding workers who possess the desired skills is seen as a major challenge, faced by 87% of firms, twice as Italy. Therefore, investing in robots might just be part of a set of numerous measures undertaken by US firms to deal with such an issue. By contrast, Italian firms attribute to robots a higher impact on improving safety conditions in the shop floor. This might explain why Italian firms have adopted more technologies for parts tracking, given they are frequently used to trace all the production processes and thus guaranteeing product safety. Overall, both countries see robot more to increase quality rather than to reduce product unit and labor cost. Table 4 synthesizes our discussion.

**Table 4. Summary of the main findings**

	Sample	US	Italy
<b>Technology Adoption</b>	- Greater adoption of digitization than automation technologies	- A higher number of firms that have adopted both automation and digitization technologies	- A lower number of firms that have adopted automation and digitization technologies  - Lower technological intensity levels due to firms' size  - Focus on Automated Parts Tracking

<sup>2</sup> This was confirmed by a question that asks respondents to report *how often a new program is written for a typical piece of computerized equipment*. We found that 51,5% of Italian plants change the program weekly or more often compared to the 24,5% of US plants. The American plants mostly change the programs monthly and yearly.

<b>Data Collection</b>	- A mix of manual and automated data collection	- Higher manually input data	- Higher use of automated data collection
<b>Organizational Architecture</b>	- Three Different clusters showing high variance	- Focus on giving production workers autonomy in equipment management	- Focus on production workers involvement in continuous improvement
<b>Robot Impacts</b>	- Impacts on Quality -Quality and safety greater than the reduction of labor and product unit cost	- Higher focus on Addressing Skill Shortage	- Higher impacts on Safety

Preliminary comparative econometric analysis shows that organizational architectures are not determinant to both adoption and intensity of adoption of technologies. The difference can be found in the impact of robots. In Italy, the negative relationship between continuous improvement and robots increasing quality seems to confirm the fact the Italian firms have not yet found proper ways to combine the problem-solving skills of workers with the adoption of robots preferring one over the other and vice versa in order to increase quality. By contrast, US firms have found proper ways to combine the autonomy of their production workers with robots for quality advancement.

Finally, regressions on production workers' wage explain that for US the new value generated by robots is appropriated to a large extent by production workers who are able to use their skills to control such equipment and increasing product quality.

APPENDIX

FACTOR ANALYSIS

*Summated Scales: Pragmatism*

Construct	Description	Sub-Construct	Item	Factor 1	Factor 2	Ordinal Alpha
Pragmatism	Production Workers Involvement in Equipment Management and Continuous Improvement using Problem-Solving and Analytical Skills	Autonomy in Equipment Management	Equipment Set-Up	-0.0023	<b>0.7568</b>	0.7357
			Modify Programs on Computerized Equipment	-0.1075	<b>0.5903</b>	
			Diagnose Equipment Problems	0.1412	<b>0.8176</b>	
		Continuous Improvement	Inspect Work-In-Progress	<b>0.5037</b>	0.1281	0.6874
			Use Quality Data to Recommend Improvements	<b>0.7657</b>	0.0465	
			Meet with Customer Personnel	<b>0.5212</b>	-0.2676	
			Use a Computer	<b>0.6524</b>	0.1475	
			Each year we expect our shop workers to make substantial improvements in their own method of operations (binary)	<b>0.4290</b>	0.0110	

*Method:* Principal Factors; *Rotation:* Oblique Promax (4); *Variance Explained* = 92,9%; N = 188.



*Summated Scales: Data-Driven Decision Making*

<b>Construct</b>	<b>Description</b>	<b>Item</b>	<b>Factor 1</b>	<b>Ordinal Alpha</b>
Data-Driven Decision Making	The degree to which decisions and are based on data.	We rarely use data regarding sources of defects in past production to modify our processes ( <i>reversed</i> )	0.4019	0.6174
		We primarily base decisions on analysis of data.	0.5934	
		Data remains in siloes; it is hard to link together data from different departments (such as HR, operations, sales). ( <i>reversed</i> )	0.6331	
		We routinely use our data to predict when a machine would fail if it does not receive maintenance.	0.5639	

*Method:* Principal Factors; N = 188.

## References

- ABOAGYE A, BAIG A, HENSLEY R, KELLY R, PADHI A, SHAFI D. 2017. Facing digital disruption in mobility as a traditional auto player. McKinsey and Company. ADLER, P.S. AND BORYS, B., 1996. Two types of bureaucracy: Enabling and coercive. *Administrative science quarterly*, pp.61-89.
- ACEMOGLU, D. AND RESTREPO, P., 2020. Robots and jobs: Evidence from US labor markets. *Journal of Political Economy*, 128(6), pp.000-000.
- AGARWAL, N. AND BREM, A., 2015. Strategic business transformation through technology convergence: implications from General Electric's industrial internet initiative. *International Journal of Technology Management*, 67(2-4), pp.196-214.
- AGRAWAL, AK, GANS J, GOLDFARB A. 2018. Prediction Machines: The Simple Economics of Artificial Intelligence. Harvard Business Review Press: Boston, MA.
- ARCIDIACONO, F., ANCARANI, A., DI MAURO, C. & SCHUPP, F. 2019. Where the rubber meets the road. Industry 4.0 among SMEs in the automotive sector. *IEEE Engineering Management Review*.
- BENITEZ, G.B., AYALA, N.F. AND FRANK, A.G., 2020. Industry 4.0 innovation ecosystems: an evolutionary perspective on value cocreation. *International Journal of Production Economics*, p.107735.
- BOSMAN, L., HARTMAN, N. & SUTHERLAND, J. 2019. How manufacturing firm characteristics can influence decision making for investing in Industry 4.0 technologies. *Journal of Manufacturing Technology Management*.
- BRESNAHAN, T.F., BRYNJOLFSSON, E. AND HITT, L.M., 2002. Information technology, workplace organization, and the demand for skilled labor: Firm-level evidence. *The quarterly journal of economics*, 117(1), pp.339-376.
- BRYNJOLFSSON, E. AND HITT, L.M., 2000. Beyond computation: Information technology, organizational transformation and business performance. *Journal of Economic perspectives*, 14(4), pp.23-48.
- BRYNJOLFSSON, E. AND MILGROM, P., 2013. Complementarity in organizations. *The handbook of organizational economics*, pp.11-55.
- CAGLIANO, R., CANTERINO, F., LONGONI, A. & BARTEZZAGHI, E. 2019. The interplay between smart manufacturing technologies and work organization. *International Journal of Operations & Production Management*.
- CETRULO, A. AND NUVOLARI, A., 2019. Industry 4.0: revolution or hype? Reassessing recent technological trends and their impact on labour. *Journal of Industrial and Business Economics*, 46(3), pp.391-402.
- COUNCIL OF ECONOMIC ADVISERS (CEA). 2016. Economic Report of the President. <https://obamawhitehouse.archives.gov/administration/eop/cea/economic-report-of-thePresident/2016> [7 September 2018]
- CIMINI, C., BOFFELLI, A., LAGORIO, A., KALCHSCHMIDT, M. & PINTO, R. 2020. How do industry 4.0 technologies influence organisational change? An empirical analysis of Italian SMEs. *Journal of Manufacturing Technology Management*.
- CORÒ, G. & VOLPE, M. 2020. 7 Driving factors in the adoption of Industry 4.0 technologies. *Industry 4.0 and Regional Transformations*.
- EAPEN, A., & KRISHNAN, R. (2019). Transferring Tacit Know-How: Do Opportunism Safeguards Matter for Firm Boundary Decisions?. *Organization Science*, 30(4), 715-734.
- ESTOLATAN, E., GEUNA, A., GUERZONI, M. AND NUCCIO, M., 2018. Mapping the Evolution of the Robotics Industry: A cross country comparison. *White Paper Series*.
- FURMAN, J. AND SEAMANS, R., 2019. AI and the Economy. *Innovation Policy and the Economy*, 19(1), pp.161-191.

- GILLANI, F., CHATHA, K. A., SADIQ JAJJA, M. S. & FAROOQ, S. 2020. Implementation of digital manufacturing technologies: Antecedents and consequences. *International Journal of Production Economics*, 229.
- HELPER, S., MACDUFFIE, J. P., & SABEL, C. 2000. Pragmatic collaborations: advancing knowledge while controlling opportunism. *Industrial and corporate change*, 9(3), 443-488.
- HELPER, S. AND KUAN, J., 2017. What goes on under the hood? How engineers innovate in the automotive supply chain. In *US Engineering in a Global Economy* (pp. 193-214). University of Chicago Press.
- HELPER, S., MILLER, J. AND MURO, M., 2018. Why undermining fuel efficiency standards would harm the US auto industry. *Washington, DC, Brookings Institution*, available at: <https://www.brookings.edu/blog/the-avenue/2018/07/02/why-undermining-fuel-efficiency-standards-would-harm-the-us-auto-industry>.
- HELPER, S., MARTINS, R. & SEAMANS, R. 2019. Who Profits from Industry 4.0? Theory and Evidence from the Automotive Industry. *Theory and Evidence from the Automotive Industry (January 31, 2019)*.
- HORVÁTH, D. & SZABÓ, R. Z. 2019. Driving forces and barriers of Industry 4.0: Do multinational and small and medium-sized companies have equal opportunities? *Technological Forecasting and Social Change*, 146, 119-132.
- IFR International Federation of Robotics. (2018). *World Robotics Report 2018*.
- JACOBIDES, M.G., MACDUFFIE, J.P. AND TAE, C.J., 2016. Agency, structure, and the dominance of OEMs: Change and stability in the automotive sector. *Strategic Management Journal*, 37(9), pp.1942-1967.
- LIN, D., LEE, C., LAU, H. & YANG, Y. 2018. Strategic response to Industry 4.0: an empirical investigation on the Chinese automotive industry. *Industrial Management & Data Systems*, 118, 589-605.
- KAGERMANN, H., WAHLSTER, W. AND HELBIG, J., 2013. Recommendations for implementing the strategic initiative Industrie 4.0: Final report of the Industrie 4.0. In *Working Group (Vol. 8)*.
- KAHLE, J.H., MARCON, É., GHEZZI, A. AND FRANK, A.G., 2020. Smart Products value creation in SMEs innovation ecosystems. *Technological Forecasting and Social Change*, 156, p.120024.
- KELLEY, MR. 1994. Productivity and information technology: The elusive connection. *Management Science* 40(11):1406-1425
- MISE, M. D. E. E. D. S. E. 2017. The Diffusion of Industry 4.0 companies and policies: 2017 Evidence.
- NOBLE, D. 1978. Social Choice in Machine Design: The Case of Automatically Controlled Machine Tools and a Challenge for Labor. *Politics and Society* 8(3-4):313-347.
- OESTERREICH, T.D. AND TEUTEBERG, F., 2016. Understanding the implications of digitisation and automation in the context of Industry 4.0: A triangulation approach and elements of a research agenda for the construction industry. *Computers in industry*, 83, pp.121-139.
- PERANI, G., COSTA, S. AND DE SANTIS, S., 2019. The Italian Industry/Enterprise 4.0 Plan: Ex-ante identification of potential beneficiaries and ex-post assessment of the use of incentives. *fteval Journal for Research and Technology Policy Evaluation*, (47), pp.78-86.
- PLANNING PERSPECTIVES, INC. 2017. Annual North American Automotive OEM – Tier 1 Supplier Working Relations Index Study. Available at: <http://www.ppi1.com/2017-annual-northamerican-automotive-oem-tier-1-supplier-working-relations-index-study/>
- RACHINGER, M., RAUTER, R., MÜLLER, C., VORRABER, W. AND SCHIRGI, E., 2019. Digitalization and its influence on business model innovation. *Journal of Manufacturing Technology Management*.
- TORTORELLA, G.L. AND FETTERMANN, D., 2018. Implementation of Industry 4.0 and lean production in Brazilian manufacturing companies. *International Journal of Production Research*, 56(8), pp.2975-2987.

- ZHENG, T., ARDOLINO, M., BACCHETTI, A., PERONA, M. AND ZANARDINI, M., 2019. The impacts of Industry 4.0: a descriptive survey in the Italian manufacturing sector. *Journal of Manufacturing Technology Management*.
- ZIRPOLI, F. & CABIGIOSU, A. 2018. Digitalization in the Italian Auto Industry. *Symphonya. Emerging Issues in Management*, 158-169.
- ZUMBO B.D., GADERMANN A.M., ZEISSER C.(2007) Ordinal versions of coefficients alpha and theta for likert rating scales. *Journal of Modern Applied Statistical Methods*, 6 (1) , pp. 21-29