3 Digital manufacturing (Robotics and 3D printing) and the evolution of manufacturing in the automotive industry

This chapter explores the main markets for the production and use of robots and 3D printing and presents a comparative analysis of the core robotics and 3D printing competences in the major world digital manufacturing sectors. We focus specifically on Piemonte and its efforts to develop CPS in the automotive sector, a traditional key driver of Italian industrial development. Particular attention is paid to the role of **collaborative robots** compared to the more traditional manufacturing robots already used heavily in automotive production.

The analysis is aimed at classifying robot technologies to understand why collaborative robots associated to sensors could revolutionize manufacturing production. The evolution of digital manufacturing and its rapid expansion are evident in many applications in the automotive value chain. The present review addresses some fundamental questions. For example, how has the automobile market changed in the most recent years? How are OEMs responding to the challenges posed by Industry 4.0? And what role can Italy (and Piemonte) play in this rapidly changing scenario?

3.1 Challenges to the Uptake of Digital Manufacturing

Despite its far-reaching effects and current advances in the relevant technologies, digital manufacturing is in its infancy. One reason for this is the conservative business strategies and averseness to unproven production processes displayed by industry (Babiceanu & Chen, 2006; Leitão, 2009). For example , a survey of 300 manufacturing leaders, conducted by McKinsey & Company (2015), indicates that only around half (48%) of firms consider themselves prepared for the impact of Industry 4.0. Another reason is related to the persistent and significant challenges involved in operationalizing digital manufacturing. First, more research is needed into autonomous systems to achieve self-organization among production cells, which would allow learning capabilities and dynamic and evolvable reconfigurations (Leitão, 2009; Brettel, et al., 2014). These advances would mean that systems could react faster, contribute more to the decision process, be more able to undertake small-lot production, and be more effective in helping enterprises identify constraints and opportunities (Brettel, et al., 2014).

In the case of Muti-Agent Systems (MAS), in particular, further research is needed on their distributive and autonomous capabilities (Shen, et al., 2006; Pěchouček & Mařík, 2008). Current technologies only allow for communication through cloud-assisted industry wireless networks (IWN) (Wang, et al., 2016). However, Holonic Manufacturing Systems (HMS) require proven design methodologies that can deliver consistency and reliability in a given system, and adaptability to available computing systems (Babiceanu & Chen, 2006). It should be noted that beyond the identified agent technologies, there is some emerging research and several projects on bio-inspired robot designs, which provide the possibility to build robots that mimic natural morphologies and self-organization (e.g. animal-like movements, self-organization and self-assembly behaviour in nature) (Pfeifer, et al., 2007).

Furthermore, research on systems autonomy must account for user adoption and firm integration. System behaviour should be predictable and stable for human workers; there is a need also to develop methodologies that support easy, fast, transparent and re-usable integration of physical automation devices (Leitão, 2009). At the firm level, local enterprise integration for Small and Medium Sized Enterprises (SMEs) is impossible due to their isolated, heterogeneous and obsolete legacy systems (Shen, et al., 2006; Brettel, et al., 2014).

In relation to firms, there are issues related to firm capabilities and cyber-security. Reconfigurable Manufacturing Systems (RMS) are impeded by lack of powerful IT systems and their integration with other systems, and inadequate employee-knowledge of production processes (Brettel, et al., 2014). Leitão (2009) raises similar issues with regard to user acceptance among enterprise managers and directors of emergent terminologies and distributed approaches to problem-solving. Realizing horizontal integration across heterogeneous institutions may also be difficult for reasons of trust, data protection and security related to firm know-how and customer information (Jazdi, 2014; Wang, et al., 2015; Brettel, et al., 2014). Existing system configurations continue to have vulnerabilities: an entire PLC network is easily accessible by a single search engine, such as SHODAN (Wang, Törngren, & Onori, 2015). In recent years, the US Department for Homeland Security (DHS) has issued warnings about hacking at industrial sites; vulnerabilities and actual hostile hackings have threatened both private and public-sector facilities systems (Wang, Törngren, & Onori, 2015).

At the shop-floor level, there are challenges related to components and agent configurations. For instance, RFID-sensor tags are impaired in the presence of water and large amounts of metal (Brettel, et al., 2014). There are problems, also, related to conflict resolution, production deadlocks and production disturbances involving intelligent agents (Wang, et al., 2016; Monostori, 2014). When human agents are introduced into the production dynamics, problems related to the optimal configuration between machine self-organization and appropriate control methods emerge (Monostori, 2014; Wang, et al., 2015). Nevertheless, the continued improvements in the pre-conditions for the smart factory seem to be addressing the issue of production deadlocks and improvements to agents' decision making are already being explored (Wang, et al., 2016). Regarding the components themselves, some important research is being carried out on digital twins which provide predictive capabilities through simulations (Rosen, 2015) and prognostics and health management techniques (e.g. a 'time machine' snapshot stored in the cloud) that can be used to increase self-awareness and self-prediction (Lee, et al., 2014; Lee, et al., 2015).

Finally, there are difficulties related to interoperability, and design and data standardization. Ontologies in existing industrial applications are often proprietary, simplistic and hierarchical structures of concepts (Leitão, 2009). Human biases (exacerbated by the presence of agents from different backgrounds) significantly influence the development of a common ontology (Leitão, 2009). While much research has been conducted on ontological methods, protocols and semantic interoperability (Pěchouček & Mařík, 2008; Wang, et al., 2016), considerable work needs to be done to integrate entire systems with related technologies (e.g. RFID technologies, wireless networks, etc. (Leitão, 2009). Table 3.1 summarizes the problems and opportunities discussed above, ranked by proximity to robotics research advancements. The research described below identifies the current state of robotics with a particular focus on robots for industrial applications. It combines publicly-available information from company press releases, news articles, peer-reviewed journals and trade and industry reports.

Table 3.1 Select Industry 4.0 challenges and research opportunities, ranked by proximity to robotics research.

Challenges	Specific issues	Research opportunities
Emergent self-organization among autonomous systems		Alternative agent systems, e.g. bio-inspired robot designs (Pfeifer, et al., 2007)
		Adaptability and prediction mechanisms in agent-based systems, particularly regarding production disturbances (Leitão, 2009; Monostori, 2014)
	Multi-agent systems (MAS)	Distributive and autonomous capabilities (Shen, et al., 2006; Pěchouček & Mařík, 2008)
		Continued investigation on ontology methods and contract net protocols (CNP) (Wang, et al., 2015)
	Holonic manufacturing systems (HMS)	Consistency, reliability, and interoperability with available computing systems (Babiceau & Chen, 2006)
Components and agent configurations	Sensor technologies	Continued development of related technologies, RFID technologies (Pěchouček & Mařík, 2008; Brettel, et al., 2014)
	Production deadlocks and agent	Introduction of digital twins that provide predictive capabilities through simulation (Rosen, et al., 2015)
	Human-machine symbiosis	Development of prognostics and health management techniques, e.g. remote diagnostics, time machine snapshots (Jazdi, 2014; Lee, et al., 2014; Lee, et al., 2015)
		Inclusion of human agents in system architecture design
		Development of user interfaces that allow for human interference, e.g. context-sensitive and context-broker systems (Gorecky, et al., 2014)
		Development of user assistance systems (Gorecky, et al., 2014)

Challenges	Specific issues	Research opportunities
Interoperability, design, and data standardization		Harmonization of ontology methods, protocols, and semantic interoperability (Pěchouček & Mařík, 2008; Wang, et al., 2016)
		Identification and understanding of the relevant information in manufacturing big data (Wang, et al., 2015)
		Continued integration of autonomous systems with related technologies, e.g. RFID technologies, wireless networks, etc. (Leitão, 2009)
		Integration and accessibility of virtual systems, e.g. virtual reality (VR), simulation (Brettel, et al., 2014; Monostori, 2014)
User acceptance	Unit predictability	Autonomous system behavior must remain predictable and stable for human workers (Leitão, 2009)
	Accessible integration	Methodologies development that supporty easy, fast, transparent and re-usable integration of physical automation devices (Leitão, 2009)
		Enterprise integration for SMEs that have isolated, heterogeneous, and obsolete legacy systems (Shen, et al., 2006; Brettel, et al., 2014)
Data protection and cyber-security		Continued development of cyber-security related technologies

Source: author's analysis

3.2 Robot Technologies

The International Organization for Standardization (ISO) and the United Nations Economic Commission for Europe (UNECE), through the 2012 ISO-Standard 8373, loosely define a robot as a reprogrammable, multifunctional manipulator designed to move material, parts, tools or specialized devices through variable programmed motions for the performance of a variety of tasks, which also acquire information from the environment and move intelligently in response. The International Federation of Robotics (IFR), the sector's main special-interest organization, and other national industry associations, such as the US' Robotics Industries Association (RIA) and the UK's British Automation & Robot Association (BARA), have adopted similar definitions (BARA, 2017b; IFR, 2017; RIA, 2017)

Various, but related developments in hardware and software technologies, academic research and the industry have enabled sustained expansion of nascent sub-sectors such as advanced industrial and practical applications. For instance, refinements to software systems are allowing robots to interact physically with the environment and also to modify it. In another installation, wide functional scope is enabling robots to become viable solutions in populated areas and almost any environment (air, land, and sea) and for any purpose (e.g.

surgery, laboratory research, defence and mass production of consumer and industrial goods) (Boston Consulting Group, 2015; Deloitte, 2015).

These continued advances can be regarded as positive for the future workplace: as better robots are developed, the possibilities increase for them to perform dangerous tasks (i.e. nuclear power plant decontamination), repetitive, stressful, labour-intensive (i.e. welding), or menial. Furthermore, robots promise cost-efficiencies and greater accuracy and reliability relative to human agents (ABB Group, 2016; PwC, 2017).

Robots vary greatly in their users and suppliers and the technologies and mechanisms used. However, it is generally agreed that robots must exhibit the sensing, intelligence and motion capabilities. The interaction among these capabilities (the "sense-think-act" formula) allows robots to perform tasks without external stimuli, thereby giving them autonomy – the technology's distinguishing feature.

Table 3.2 Robotics capabilities and definitions.

Ability	Definition
Sensing	Robots employ sensing technology to acquire information about their environment.
Intelligence	Robots process information captured through sensor technology and produce outputs for decision making, coordination, and control.
Motion	Robots automatically follow instructions that are pre-programmed or generated in real-time based on sensor input to perform a deliberate, controlled, and often repeated, mechatronic action, including point-to-point mobility.

Source: ABI Research, 2016.

While there are innumerable possible hardware and software combinations that can be regarded as robots, all machine systems share a number of core components in their construction – these include sensors, end effectors and control systems (Consortium on Cognitive Science Instruction, 2017).

Sensors allow robots to 'perceive' their environment, thereby allowing an entire machine system to respond appropriately. Sensors enable monitoring of parts locations and machine orientations during production, which allow the robot to compensate for any variation in processes (Society of Manufacturing Engineers, 2017). Some important sensor types include visual, force and torque, speed and acceleration, tactile, and distance sensors (although the majority of industrial robots utilize only binary sensing) (USLegal, 2017). More complex sensor types include: Light Detection and Ranging (LIDAR) abilities that use lasers to construct three dimensional maps of the robot's environment, high frequency sounds-based supersonic sensors, and accelerometers and magnetometers that allow the robot to sense its movement relative to the Earth's gravitational and magnetic fields (Consortium on Cognitive Science Instruction, 2017).

Robots (particularly in industrial applications) require an end-effector or an end of arm tooling (EOAT) attachment to hold and manipulate either the tool performing the process or the piece upon which the process is being performed (MHI, 2017). The most common end-effectors are general-purpose grippers, the most common of these being finger grippers with two opposing fingers or three fingers in a lathe-chuck position; the grippers' strength is augmented by pneumatics and hydraulics and through the inclusion of additional sensors may be equipped with sensory capabilities (BARA, 2017a; Consortium on Cognitive Science Instruction, 2017; USLegal, 2017).While these components are coordinated by the robot's controller, end-effectors require to be operated and powered independently and need changing should the system have to be refitted for another task (US Patent and Trademark Office, 2017).

The robot's actions are directed by a combination of programming software and controls, which give the system automated functionality allowing for continuous operation (MHI, 2017). Available robot control systems range from simple pre-programmed robots, which perform the simplest operations, to more complex robots that are able to respond appropriately in increasingly complicated environments (Consortium on Cognitive Science Instruction, 2017). Industry observers predict that innovation in software and AI will be fundamental to the development of next-generation robots (Keisner, Raffo, & Wunsch-Vincent, 2015). Industry stakeholders believe that the continuing reductions in sensor prices and the increasing availability of open-source robot software will drive the technological possibilities of robots (Anandan, 2015).

3.2.1 Robotics classifications

Robots can be classified in various ways - according to their mechanical structures and mechanisms. Some of the most common approaches involve using the robot's' mobility, work envelope shape (robot's area of operations, determined by its coordinate system, joints arrangements, and manipulator length), and kinematic mechanisms (the movement allowed by the joints between robot parts) (Zhang, et al., 2006; Asada, 2005; Lau, 2005; Ross, Fardo, et al., 2010) as the bases for differentiation.

The IFR and industry more generally favour two industry classifications of robots according to their purpose : Industrial Robots (IR) and Service Robots (SR)[14].

An IR is an automatically controlled, reprogrammable, multipurpose manipulator, programmable along three or more axes, which can be fixed or mobile for use in industrial automation applications (ISO 8373, 2012). Table 3.3 provide a list of the available IRs ranked their mechanical structure and industrial application.

[14] For a classification of Service Robots, see Table III.1 and III.2 in Appendix

Table 3.3 Industrial robots (IRs) classification by mechanical structure and application.

Category	Description	Industrial application
Linear robots (Cartesian and gantry robots)	Cartesian robot whose arm has three prismatic joints and whose axes are coincident with a Cartesian coordinate system	Handling for plastic moulding Sealing Laser welding Pressing
SCARA robots	A robot, which has two parallel rotary joints to provide compliance in a plane	Assembly Packaging
Articulated robots	A robot whose arm has at least three rotary joints, great payload capacity and flexible mounting possibilities for optimizing working range; might be combined with SCARA elements	Handling for metal casting Welding Painting Packaging Palletizing Handling for forging
Parallel robots (delta)	A robot whose arms have concurrent prismatic or rotary joints	Picking and placing Assembly Handling
Cylindrical robots	A robot whose axes form a cylindrical coordinate system	Medical robots (DNA screening, forensic science, drug development and toxicology)
Others		Robots in Hazardous Environments Operations under water Operations in atmospheres containing combustible gases Operations in space
Not classified		Automated guided vehicles (AGVs)

Source: Strujik, 2011, International Federation of Robotics, 2015

Interactive robots (often called *social robots*) are an emerging sub-set of robotics that envisage the next-generation robotic systems. These robots are expected to be viable in human environments involving various forms of interactions with human agents, and are intuitive, easy-to-use and responsive to user needs (Christensen, Batzinger, et al., 2016). Because their commercialization is in its infancy, the IFR classifies interactive robots as either IRs or SRs, which latter include the sub-set of social robots that exhibit social characteristics (KPMG, 2016).

While the realization of such systems is extremely complex and restricted (ABB Group, 2016; Christensen, Batzinger, et al., 2016), a cooperative environment involving human agents and automated systems are an attractive proposition because of their distinct advantages relative to other configurations: they would combine the flexibility and adaptability of the former in complex tasks, with the consistency and high productivity in simple tasks of the latter (Michalos, Makris, et al., 2010).

Contemporary human-machine configurations in the workplace vary based on the form of support that the robot can provide to the agent – often depending on the degree of assistance that the combination of sensors, actuators and data processing within the system can provide. Generally, robot systems and human agents perform their tasks either jointly or separately. The level of interaction is strongly influenced and limited by the ability of the entire environment to avoid collisions with human agents. Interactive robots promise to deliver cooperation that goes beyond collision avoidance (Krüger, Lien, & Verl, 2009).

Current IRs fall into several different categories: 1) robot assistant, 2) collaborative robots (co-bots) and 3) humanoid or anthropomorphic robots. Robot assistants are interactive and flexible robotic systems that provide sensor-based, actuator-based and data processing assistance (Helms et al., 2002). First designed by the German non-profit Fraunhofer Institute for Manufacturing Engineering and Automation (Fraunhofer Institute IPA), current-generation robot assistants are complex mechatronics systems that consist of mobile platforms with differential gear drives and energy supply for autonomous workflow (Krüger, Lien, & Verl, 2009). These are often multifunctional, adaptable to varying requirements of automation, and provide interactive guidance to the user (Pew Research Centre, 2014).

Collaborative robots or co-bots are human-scale, articulated robots that directly work with human agents. Invented by Northwestern University McCormick School of Engineering professor Edward Colgate (alongside Michael Peshkin), these are mechanical devices that provide guidance through the use of servomotors while a human operator provides motive power (Krüger, Lien, & Verl, 2009; Morris, 2016). In practice, the co-bots' distinct feature is their ability to directly provide power support to the human agent in strenuous tasks, while maintaining a high degree of mobility (Lau, 2009). While co-bots tend to be employed in manufacturing tasks,[15] they are also used in non-traditional applications such as surgery (Delnondedieu & Troccaz, 1995) (see Table 3.4 for a list of popular collaborative robot types).

Humanoid or anthropomorphic robots act autonomously and safely, without human control or supervision. They are not designed as solutions to specific robotic needs (unlike robots on assembly lines), but built to work in real-world environments, interact with people and adapt to their needs (Coradeschi & Ishiguro, 2006; PwC, 2017). The human-inspired design of humanoid robots is combined with a safe, lightweight structure (Krüger, Lien, & Verl, 2009). Generally, these robots are designed for applications that IRs do not cover (World Technology Evaluation Centre, 2012): assembly processes where position estimation and accuracy of the robot are significantly below assembly tolerance, tasks where the robot works closely with (and may interact directly with) human agents, and processes where the robot target's dimensions are relatively uncertain (Albu-Schaffer, Haddadin, et al., 2007).

[15] The employment of co-bots in industrial applications, particularly in the automotive sector, will be explored in the later sections.

Table 3.4 Prominent types of collaborative robots.

Type	Summary	Applications
Power and Force Limiting	Incidental contact initiated by the robot is limited in energy to not cause operator harm.	Small and highly variable applications
		Conditions requiring frequent operator presence
		Machine tending
		Loading and unloading
Hand Guiding	The operator leads the robot movement through direct interface	Robotic lift assist
		Highly variable applications
		Limited or small-batch productions
Speed and Separation Monitoring	Robot speed reduces when an obstruction is detected	Simultaneous tasks
		Direct operator interface
Safety-rated Monitored Stop	Co-bot responds promptly (stopping or moving) in the presence of its operator	Direct part loading or unloading
		Work-in-process inspections
		Speed and separation monitoring (stand-still function)

Source: Robotic Industries Association, 2014

3.3 Global competition and markets in the robotic industry [16]

The robotics industry has experienced rapid growth in recent years. A comparison based on robotics expert, Frank Tobe's industry-dedicated database, the Robot Report's snapshots of firms and research institutions in 2012 and 2015, is indicative of the sector's rapid growth. The institutions' geographical data suggest geographical agglomeration: start-ups and service robotics companies are located near prominent universities and research institutions (e.g. Carnegie Mellon, MIT, Harvard, UC Berkeley, Stanford) or areas of innovation (e.g. New York city), while industrial robot companies are prevalent in traditional industrial regions (e.g. Germany and the UK) (Tobe, 2012). The sector's activity is further highlighted by the increasing sources of funding for robotics-related ventures and consolidation among existing robotics firms. Tobe's 2016 data in the Robot Report on mergers and acquisitions (M&A) (Tobe, 2017a) and funding-related activities (Tobe, 2017b) reinforce the industry's activeness. Funding of robotics-related startups reached USD 1.95 billion (50% more than in 2015) while M&A activity accounted for at least USD 18.867 billion. Overall, the data

[16] For a summary of key-findings at country level, see Table III.4 in Appendix

suggest some interesting developments: 1) Chinese companies are positioning themselves aggressively in the industry (e.g. the USD 5.1 billion acquisition of German robotics KUKA AG by Chinese consumer products manufacturer, Midea Group); 2) large blue-chip US firms are acquiring robotics start-ups (e.g. Honeywell International Inc.'s acquisition of materials handling solutions firm, Intelligrated, for USD 1.5 billion, USD 0.6 billion acquisition of start-up Cruise Automation, which is developing auto-pilot systems for existing cars of General Motors); and 3) the sustained success of Silicon Valley startups in raising funds (5 of the top 10 companies by amount funded in 2016, are in Silicon Valley or in the greater California area).

IFR 2015 unit sales data indicate that China has become the largest robotics market, with an installed count of 68,000 industrial robots (a 20% increase on 2014 figures). Both the US and Germany remain key robotics markets with peaks of 27,504 units (up 5% in 2014) and 20,105 units (up from 20,051 units in 2014) respectively. The US is the fourth-largest robots market, and Germany the fifth-largest. During the same period, UK sales decreased to 1,645 units.

The sustained growth of the industrial robotics market is attributable mostly to the automotive sector: robotics sales CAGR from 2010 to 2015 was approximately 20% and the 2015 sector installed count approximated 97,500 units (or 38% of the total robotics supply at the time) (International Federation of Robotics, 2016). Other valuable sectors that the IFR analysis (2016) identifies are the electrical and electronics (install count of 64,600 units in 2015) and metal and machinery (29,450 units); sales to all industries sales (except for automotive and electrical and electronics) in 2015 increased by 27% on average.

Relative to the industrial robots' market, the service robots market remains a nascent sub-sector. IFR (2015) unit sales data show that sold units in 2015 reached 41,060 units. Sales of service robots for professional use were largest in logistics (19,000 units or 46.27% of the total unit supply), defence (11,207 units or 27.29%), field (6,4440 units or 15.68%), and medical (1,324 units or 3.22%) (IFR, 2015). The IFR (2015) forecasts that these applications will remain key growth segments for service robotics from 2016 to 2019.

Collaborative robots. While still in its infancy, the collaborative robots (or co-bots) sub-sector is expected to drive growth in the industry significantly. Despite achieving market acceptance and recognition only quite recently (Lawton, 2016; Universal Robots, 2016), it is already a multi-million dollar market (approximately USD95 million in 2014) (Tobe, 2015) and (alongside the digitization of mechanical systems) is a hot topic among industry stakeholders (e.g. collaborative robots as one of the main themes in AUTOMATA 2016, one of the sector's most prominent trade conventions) (Tobe, 2016). Some of the major players in the category include Rethink Robotics, a producer of the popular robots Baxter and Sawyer, and Universal Robotics, makers of the world's first co-bot and the current market leader by install base (Universal Robotics, 2016a; Universal Robotics, 2016b) (Table 3.5 provide a list of selected robotics companies producing co-bots).

Analysts and stakeholders alike are optimistic that it will become a billion-dollar trade by 2020, with some more bullish than others (such as Barclays Capital which forecasts a market valuation of USD 3 billion by 2020) (ABI Research *in* Lawton, 2016; Zalenski, 2016; Universal Robots *in* Thor, 2017). Europe is expected to maintain a significant role in the market's development for several reasons including: 1) the strong presence of European robotics manufacturers in the global landscape; 2) the activeness of European companies in maintaining their advantage in the emerging co-bot market (e.g. Universal Robotics, ABB Group, KUKA); and 3) the strong robotics research base in the region (e.g. Fraunhofer Institute) (Bogue, 2015).

There are various aspects feeding the appetite for co-bots. First, the greater human-robot collaboration enabled by co-bots has resulted in greater productivity on the shop floor (Shah, 2011). Early adopters, particularly established carmakers such as Ford, Mercedes Benz and Toyota, have achieved productivity gains from using co-bots alongside additional human workers (Nisen, 2014; WEF, 2016; Zalenski, 2016)

Furthermore, unlike traditional industrial robots that are large in size and require significant investments (making them ideal for mass production), co-bots are compact and easy-to-use, making them viable solutions for the untapped SME market and low-volume and high-mix production (Lawton, 2016; Zhang, 2017). In addition, co-bots are affordable: Rethink Robotics' Baxter and Sawyer, cost around USD 25,000-30,000 (22,880.50 EUR to 27,456.60 EUR)[17], Universal Robotics' products range in price from USD 23,000 to USD 45,000 (21,050.06 EUR to 41,184.90) (Tobe, 2015), and co-bot variants are often available for 20,000 EUR to 40,000 EUR (Bogue, 2015). Bogue (2015) adds that these robots often have short payback periods, generally one year or less.

Finally, the co-bots' design features address safety concerns often associated to traditional industrial robots. Co-bots are designed with rounded surfaces (to reduce the risk of impact, pinching and crushing), and are equipped with integrated sensors to detect human presence (and to stop in such conditions) and force-limited joints (to sense forces due to impact) (Tobe, 2015; Zalenski, 2016; Zhang, 2017). Thus, manufacturers (and even service providers) are able to employ co-bots in a variety of ways that are beyond the capabilities of industrial robots (Tobe, 2015; Lawton, 2016b; Universal Robotics, 2016).

[17] FX rate on December 31, 2015 (date of report publication) was 1 USD = 0.91522 EUR (via exchange-rates.org).

Table 3.5 Collaborative robots of select companies.

Company	Base of operation	Co-bot	Feature summary	Product status	Base price (in USD)
Rethink Robotics	North America	Baxter	2-armed co-bot	On sale	25,000.00
		Sawyer	1-armed co-bot	On sale	29,000.00
Universal Robotics	Europe (Denmark)	UR3 robot	3-kg payload capable co-bot	On sale	23,000.00
		UR5 robot	5-kg payload capable co-bot	On sale	35,000.00
		UR10 robot	10-kg payload capable co-bot	On sale	45,000.00
MRK-Systeme	Europe (Germany)	KR5 SI robot	Co-bot software for robot systems	NA	NA
F&P Personal Robotics	Europe (Switzerland)	P-Rob 2	1-armed co-bot	On sale	NA
Robert Bosch GmbH	Europe (Germany)	APAS System	1-armed co-bot	In-house use	NA
ABB Group	Europe (Germany)	YuMi	2-armed co-bot	On sale	40,000.00
MABI Robotic	Europe (Switzerland)	Speedy 6 robot	6-kg payload capable, 1-armed co-bot	On sale	NA
		Speedy 12 robot	12-kg payload capable, 1-armed co-bot	On sale	NA
FANUC Corporation	Japan	CR-35iA	35-kg payload capable 1-armed co-bot	On sale	NA
KUKA	Europe (Germany)	LBR iiwa	13.64-kg payload capable, 1-armed co-bot	On sale	100,000.00
Kawada Industries	Japan	HRP humanoid robot	2-armed co-bot	On sale	60,000.00

Source: Adopted from Tobe (2015); Co-bots guide (https://cobotsguide.com); various company websites

Warehouse automation and logistics robots. The continued growth of e-commerce is expected to sustain the appetite for warehouse and logistic robotics. Amazon's USD775 million purchase in 2012 of market-leading Kiva Systems (now, rebranded Amazon Robotics) (Rusli, 2012) has served as proof-of-concept for the logistics industry regarding the benefits of warehouse automation. Shifting consumer expectations have increased pressure on service providers to automate. Industry estimates suggest that the robotic market's valuation could be around USD20 billion by 2020 (Tractica, 2017).

While Amazon's acquisition left the sector with no established leader in 2012, a combination of start-ups and acquisitions has filled the gap. Some of the more notable startups include: 1) Locus Robotics, a spin-off founded by Massachusetts-based Quiet Logistics to provide warehouse automation solutions to third-party logistics providers (with DHL Supply Chain, as its most notable client); 2) Fetch Robotics, a San Jose, California-based producer of the mobile cargo system 'Freight' and the mobile manipulator 'Fetch' (both of which work collaboratively with human agents in the facility); and 3) Aethon, Inc., a producer of Automated Guided Vehicles (AGVs) that are used also in hospitals (Banker, 2016; Romeo, 2016; Clark & Bhasin, 2017). Apart from these enterprises, established firms are developing (or acquiring) their own logistics automation solutions: e.g. 1) KUKA's acquisition of materials handling and logistics automation provider Swisslog; 2) Toyota Industries' purchase of Netherlands-based Vanderlande Industries, another materials handling and logistics automation provider; and 3) Hitachi's Racrew, its mobile warehouse robotics system that is in development (Banker, 2016; Capron, 2017) (Table 3.6 provide a list of selected robotics companies producing warehouse and logistic robots).

Various developments have made warehouse and logistics automation an attractive proposition. First, Amazon's deployment of robotic systems in 2012 demonstrated substantial cost reductions and productivity gains in warehouse management – recent research suggests that the firm is saving around USD 22 million in each fulfilment centre equipped with Amazon robots (Kim, 2016). Moreover, current-generation automation solutions are more adaptable, flexible, and intelligent, thereby allowing service providers to maintain zero-defect logistics processes and to rapidly expand services and facilities (D'Andrea *in* ROBO Capron, 2017; Parsons, 2017).

Third, shifting consumer expectations (due to the rise of e-commerce) have put pressure on service providers to adopt automation technologies. In particular, the introduction of same-day deliveries (and the preference for fast delivery among consumers) has resulted in various challenges in logistics and warehouse management including: 1) maintenance of multiple distribution facilities which often are located in rural areas and face labour-related challenges' 2) exacerbation of the 'last-mile' problem, as goods are no longer delivered to retail stores, but directly to households. Robotics seemingly offer viable solutions to these problems (Clark & Bhasin, 2016; Romeo, 2016; Harnett & Kim, 2017; Bray, 2017).

Table 3.6 Warehouse automation and logistics robots of select companies.

Company	Base of operations	Robotic solutions features	Product status
Kiva Systems (Amazon Robotics)	North America	Autonomous mobile robot systems for orders fulfillment	In-house use
Locus Robotics	North America	Autonomous mobile robot systems for orders fulfillment	On sale
Fetch Robotics	North America	Autonomous mobile robot systems for orders fulfillment	On sale
Vecna Technologies	North America	Autonomous mobile robot systems for orders fulfillment	On sale
InVia Robotics	North America	Autonomous mobile robot systems for orders fulfillment	On sale
IAM Robotics	North America	Autonomous mobile robot systems for orders fulfillment	On sale
6 River Systems	North America	Autonomous mobile robot systems for orders fulfillment	In development
Magazino GmbH	Europe (Germany)	Autonomous mobile robot systems for orders fulfillment	On sale
Hitachi Solutions	Japan	Autonomous mobile robot systems for orders fulfillment	In development
Clearpath Robotics	North America	Autonomous guided vehicles	On sale
Aethon	North America	Autonomous guided vehicles	On sale
Grezenbach Maschinenbau GmbH	Europe (Germany)	Autonomous guided vehicles	On sale
Knapp AG	Europe (Austria)	Autonomous guided vehicles	On sale
KUKA Swisslog	Europe (Switzerland)	Autonomous guided vehicles	On sale
MiR Mobile Industrial Robots	Europe (Denmark)	Autonomous guided vehicles	On sale
Starship Technologies	Europe (Estonia)	Autonomous guided vehicles	In development
Dispatch	North America	Autonomous guided vehicles	In development

Company	Base of operations	Robotic solutions features	Product status
Grey Orange India Private Ltd.	India	Autonomous goods-to-person system	On sale
Scallog	Europe (France)	Autonomous goods-to-person system	In development
RightHand Robotics	North America	Grasping technology	In development
Google, Inc.	North America	Unmanned aerial vehicles	In development
Balyo	Europe (France)	Vision systems for logistics automation	In development
Seegrid Corporation	North America	Vision systems for logistics automation	In development

Source: Adopted from Banker (2016); Romeo (2016); Tobe (2016); Bray (2017); various company websites

3.3.1 US

Overview. The US is an important robotics player, being the fourth-largest robots market by sales in 2015 and home to the most robotics startups (IFR, 2016c; IFR 2016d). Much of robotics' growth in the country comes from American industries' efforts to maintain competitive advantage through production automation (IFR, 2016a). Moreover, US robotics is a mature sector: it comprises a number of leading robotics research institutions (Carnegie Mellon University, MIT), subsidiaries of foreign companies (ABB Group, KUKA AG, FANUC), notable robotics startups (Boston Dynamics) and the largest technology companies (Google, Amazon) that are delving into robotics.

Industry and technical support. Across the US, there are three prominent robotics clusters: 1) Boston, Massachusetts; 2) Pittsburgh, Pennsylvania and 3) Silicon Valley, California. Boston seems the most mature among the three: it is already a thriving robotics hub, with 100 companies and 3,000 robotics employees and attracting multi-million investments annually (Subbaraman, 2015). It is also home to a number of robotics companies with diverse specializations (e.g. Amazon's Kiva Systems, the largest US household robot provider iRobot Corporation, and prominent start-up Boston Dynamics), a number of universities with robotics programs (MIT, University of Massachusetts Lowell, and Olin College of Engineering) and various industry partnerships (e.g. Google's Project Wing with MIT, Toyota's commitment with MIT's Computer Science and Artificial Intelligence Laboratory) (Subbaraman, 2015).

Pittsburgh hosts the CMU (a major actor in the ARM institute),[18] one of the leading US universities for robotics, and a healthy ecosystem of venture capitalists with robotics expertise (e.g. General Electric Ventures, The Robotics Hub) and various university spinoffs

[18] To be discussed in the succeeding sections.

and startups (e.g. high-tech baby gear producer, 4moms, and bipedal robots' developer, Agility Robotics) (Anandan, 2016).

While known more as an ICT innovation cluster, Silicon Valley is home also to various robotics enterprises and startups, particularly those involved in SRs and AI. Most of the Valley's robotics projects are international in scope and attract interest from both established and emerging institutions (e.g. Bosch, Fetch Robotics, SRI International) (Anandan, 2016).

The Robotic Industries Association, founded in 1974, is the sector-dedicated trade group in North America. Member organizations include leading robot manufacturers, users, systems integrators, component suppliers, research groups and consulting firms (Robotics Industries Association, 2017).

Institutional support. In 2011, the US Government launched the Advanced Manufacturing Partnership (AMP) to drive investments and collaboration between industry, academia, and government in emerging technologies related to manufacturing (National Institute of Standards and Technology, 2011). Through AMP, in the same year, multiple federal agencies, including the National Science Foundation (NSF), the National Aeronautics and Space Administration (NASA), the National Institute of Health (NIH), and the US Department of Agriculture (USDA), launched the National Robotics Initiative. With annual funding of around USD 40 million to USD 50 million, the programme sought to accelerate the development and adoption of next-generation robotics in the US through the development of fundamental research (National Science Foundation, 2011). In 2016, the NSF released the National Robotics Initiative 2.0: Ubiquitous Collaborative Robots (NRI-2.0) to serve not only as a continuation of the original programme but also to promote research on the scalability and variety of next-generation robotics (Computing Community Consortium, 2017).

More recently, the US Department of Defense (DoD) announced the new Advanced Robotics Manufacturing (ARM) Innovation Hub award to American Robotics, Inc. in Pittsburgh, Pennsylvania (US DoD, 2017). The US DoD (2017) stated that the American Robotics, Inc., a consortium of stakeholders from both the public and private spheres, had contributed USD 173 million (around 162.56 million EUR[19]); federal government is matching it with a budget of USD 80 million (approximately 75.17 million EUR). The ARM institute will include 123 industry partners, 40 academic and academically affiliated partners, and 64 government and non-profit partners (US DoD, 2017). The ARM programme joins the larger Manufacturing USA programme, a federal-sponsored network of industry, academic, and federal stakeholders that is investigating identified high-potential technologies in future manufacturing (among others, biopharmaceuticals, regenerative manufacturing, AI) to sustain the country's competitiveness (Manufacturing USA, 2014).

The ARM Institute is spearheaded by Carnegie Mellon University (CMU) and is focused on critical growth manufacturing sub-sectors which forecasts high levels of robotics adoption (e.g. aerospace, automotive, electronics, textiles, logistics, and composites) (ARM Institute, 2017b). To expand its reach, the institute is launching eight Regional Robotics Innovation Collaborative (RRICs), which are semi-autonomous institutes that will facilitate the

[19] FX rate on 13 January, 2017 (date of report publication) was 1 USD = 0.93964 EUR (via exchange-rates.org).

networking of manufacturing and robotics companies and accelerate the adoption of robotics within their regions (ARM Institute, 2017a).

Demand-side trends. Besides the continued demand from American manufacturers for production automation, another notable demand-side development is related to the aggressiveness of US technology companies in acquiring robotics companies or researching related technologies. A prominent case is the online retailer Amazon's acquisition of warehouse automation provider, Kiva Systems, to improve productivity in its facilities (Guizzo, 2012). Another is Automatic Test Equipment provider Teradyne's acquisition of Universal Robots (UR) in 2015 in order 1) to maintain its competitive advantage in its core offerings, as its customer base clamoured for the automation of the manual processes around its testing offerings, and 2) to participate in the emerging co-bot market in which UR holds a near 60% market share (Robotics Business Review, 2015). Other examples include investments by technology companies, such as Google, of USD20 to 30 billion in AI R&D (Columbus, 2017).

While the US remains an innovation hub and an important robotics market, there are concerns that none of the established market sector leaders are US companies (Cuban 2016; Statt, 2017). Many important US players are subsidiaries of foreign companies and the notable US robotics companies often serve niche or nascent demand.

3.3.2 China

Overview. China was the largest robotics market by sales in 2015, with an installed count of 68,000 industrial robots (a 20% increase on 2014 figures) across its provinces (IFR, 2016). IFR (2016) statistics suggest that China will continue to be a net importer, with foreign robot suppliers maintaining an approximately 70.12% market share. Increasing labour costs in China, brought about by the mass movement of Multi-national Enterprises (MNCs) to China during the 1980s and the country's ageing workforce, have driven manufacturers to adopt robotics in their production processes (Bland, 2016). MNC-owned Chinese factories are prominent in the robot drive: Ford's Hangzhou facility features over 650 IRs while similar machines are found in General Motors' Shanghai and Wuhan factories (Bradsher, 2017).

Apart from its market size, China, through its domestic firms, has remained in the headlines because of its continued aggressiveness in acquiring several foreign robotics companies. Since 2015, the Chinese have been involved in numerous landmark acquisition deals including AGIC Capital's purchase of Italian end-of-arms tool supplier GIMATIC Srl, AGIC and state-funded Guoxin International Investment Corp.'s purchase of German IR integrator KraussMaffei Group, and the USD5.2 billion takeover of German KUKA AG by the Chinese Midea Group (Tobe, 2015).

Industry and technical support. Industry support is mainly from the China Robot Industry Alliance (CRIA), an association of Chinese manufacturers, robot end-users, research institutes, colleges and universities which is supported by various Chinese government agencies and the China Machinery Industry Federation (CMIF) (CRIA, 2015). Founded in April 2013, it has 152 member organizations (DGI, 2016).

CRIA aims to become a platform for various stakeholders to promote the use and development of robotics in China, whilst also ensuring that the overall direction follows both national industrial policies and market trends (CRIA, 2015b). CRIA was instrumental in developing China's national standards for industrial robots; it is currently working on standards for service robotics (The State Council of the People's Republic of China, 2016).

Institutional support. Industry observers believe that the Chinese effort in robotics is indicative of China's drive to become market leader in manufacturing and manufacturing innovation, as embodied in the 'Made in China 2025' (MiC 2025) plan. MiC 2025 is the first of three comprehensive plans to upgrade Chinese industry and transform China into a manufacturing power by 2049 through the adoption of advanced manufacturing technologies from abroad and the promotion of domestic brands and R&D capabilities (Xinhua News Agency, 2015). Some of the specific targets identified by MiC 2025 for the Chinese robotics industry are related to promotion of various robotics-related research for industrial applications and investigations in high-potential sub-fields such as SRs and social works robotics (MIIT, 2016) (details of MiC 2025's sector-specific Robot Industry Development Plan are provided in Table 3.7).

Table 3.7 Details of China's Robot Industry Development Plan

Objective	Specific targets
Larger production scale	Domestic robot supply > 100k units
	6-axis robots > 50k units
	SRs revenue > 30 billion RMB
Elevated production capabilities	Reach of international standards on Mean Time Between Failures (MTBF)
	Advancement in key robot technologies
Breakthrough in core components	CN firms' share in domestic market > 50%
	Capabilities to produce own robot components
Significant achievement in integrated solutions	Robot density > 150 robot units per 10,000 workers
	Integrated robot solutions > 30 solutions in traditional industries

Source: Macquarie Research (2016)

While details of exact sums and policy strategies expected from the Chinese are scarce (Lee, 2015), there is significant activity at the provincial level. For instance, the province of Guangdong promised to invest USD 8 billion for automation-related projects in 2015 to 2017 (Bland, 2016). Knight (2016) has a higher estimate: USD 150 billion to equip Guangdong factories with IRs and to establish two new centres for advanced automation (Knight, 2016). Lianoning's provincial capital, Shenyang, has launched a USD7 million fund to support high-technology industries (Schuman, 2017).

Firm-level information. At firm-level, local Chinese companies are launching robotics-focused enterprises and subsidiaries to challenge established robotics firms in product pricing (Bland, 2016). Bland offers an example: Shanghai-listed machine producer for the plastics sector, Ningbo Techmation, has launched a subsidiary, E-Deodar, which produces IRs for the plastics industry that are 20–30% cheaper than that produced by ABB and KUKA. Another case is Chinese technology giant Baidu's various investments and partnerships in AI and machine learning (Bajpai, 2017).

Contemporary issues. Despite the broad-based efforts in Chinese private and public sectors, observers have raised several concerns about the nation's manufacturing aspirations. First, China's manufacturing sector, relative to the global competition, draws most of its competitive advantage from labour-intensive production. Statistics suggest that it remains low-technology based (2016 value-added share was only 19% while more developed countries, e.g. the US and Germany, achieved around 30%) and its R&D capabilities remain weak (most are in developed regions) (Euromonitor International, 2017). Despite being the largest robotics market, analysts believe that China remains a laggard in industrial automation: only 60% of Chinese companies use industrial automation software (e.g. Enterprise Resource Planning) and robot density is only at 49 units per 10,000 employees (Lee, 2015; IFR, 2016). Moreover, correspondence with Chinese companies reveals that they are focused mainly on production automation rather than holistic integration of value chains through data analytics (espoused by programmes such as Industry 4.0) (Meyer, 2016). Realizing MiC 2025's vision requires a broader effort from the Chinese government since firm capabilities remain uneven (Wang, 2017).

Particular to the Chinese robotics landscape, is continued over-investment and population instability: observers not the rapid establishment of different small robotics companies and lack of established Chinese robotics components (e.g. speed reducers, servo-motors, and control panels) manufacturers, which may prevent the sector from achieving scale (Tobe, 2017). Analysts predict that it could take China between five and ten years to produce firms and products on a par with their German and Japanese counterparts (Macquarie Research, 2016a; Manjoo, 2017).

Related to debt financing at the local level, observers worry that there is over-capacity in local governments' debt instruments as Chinese municipalities race to participate in the robotics sector (Taplin, 2016). Taplin (2016) describes the case of Wuhu city, west of Shanghai and situated in Anhui province: to establish its robotics park, it has already incurred a debt of USD 332 million and is planning to raise an additional USD 181 million to sustain developments.

Last, a confluence of factors (such as cost pressures and an emphasis on automation) have led to some factories across China indiscriminately adopting advanced automation processes and robotics. Knight (2016) describes a Shanghai-based Cambridge Industries Group (CIG) factory that already is adopting machines to replace Chinese workers and is planning entirely-automated factories or 'dark factories'. In another example, Taiwanese consumer electronics manufacturer, Foxconn Technology Group, has plans to fully automate its Chinese factories; the firm has stated that already it can produce 10,000 units of its Foxbots, IRs that can replace human labour (Statt, 2016). Industry observers are worried that such actions could jeopardize the country's still-enormous manufacturing workforce (Knight, 2016). Some believe that as complex manufacturing tasks are automated, most Chinese workers will be forced to move into the services sector (Williams-Grut, 2016).

3.3.3 Japan

Overview. Japan is a powerhouse in the robotics landscape: it was the third-largest robot market by sales in 2015 (IFR, 2016). IFR (2016) data indicate that Japan has seen a growing trend of 10% on average since 2010 following decreases between 2005 and 2009.

Japan's sustained performance in the robotics sector stems from how the Japanese view robots more than machines, as social agents that embody Japanese culture. How the Japanese regard robots is based mostly on their view of technological progress as a cultural phenomenon (Samani, et al., 2013). Often, Japanese scientists and engineers incorporate traditional cultural and social narratives and values into their robotics developments (Šabanović, 2014). Robotics has become pervasive in Japan beyond traditional applications, and enjoys high levels of social acceptance on the island.

Thus, it is unsurprising that Japan produces most of the world's robots (EU-Japan Centre for Industrial Cooperation, 2015). Japanese firms are increasingly export-oriented: already 65% of production is for exports, with the remaining third for the domestic market (primarily because of shrinking domestic prices and an already saturated market) (EU-Japan Centre for Industrial Cooperation, 2015). It is of no surprise that Japan is home to three of the world's top robotics companies by installed base in 2015: FANUC Corporation (with the largest robot installed base of 400,000 units), Yaskawa Corporation (with the second-largest installed base of around 300,000 units), and Kawasaki Heavy Industries, Ltd (with the fourth-largest installed base of around 110,000 units) (Montaqim, 2015).

Japanese companies produce a wide variety of robotics: in manufacturing, there are IRs for automotive, E&E, chemicals, machinery and metal processing and logistics applications (EU-Japan Centre for Industrial Cooperation, 2015). The EU-Japan Centre for Industrial Cooperation report (2015) explains that while Japan is engaged in both IR and SR production (and adheres to the IFR industrial classification), it has a particular strength in the production of high-precision servomotors, cables and many different sensor types and components essential for robot construction and maintenance – industry stakeholders have assigned them the separate classification 'RoboTech'.

The Japanese New Energy and Industrial Technology Development Organization (NEDO) and the Ministry of Economy, Trade and Industry (METI) forecast that the Japanese robotics sector will double in value by 2020 and that growth from 2020 to 2035 will be around 10% to 15%. NEDO projects are increasing also in areas where Japan enjoys a competitive advantage (e.g. RoboTech production).[20]

Industry and technical support. Japanese robotics enjoy strong institutional support; robotics-related research is funded by the Japanese government through various government agencies including: METI, NEDO, Advanced Telecommunications Research Institute International (ATR), Agency for Advanced Industrial Science and Technology, National Institute of Environment and Disaster Prevention, Japan Science and Technology Agency,

[20] NEDO expects the RoboTech sector to grow 20% annually in the next 5 years.

Ministry of Education, Culture, Sports, Science and Technology, Bio-Mimetic Control Research Centre, Ministry of Land Infrastructure and Transport to name a few. A notable example is the Japan National Research and Development Institute of Science and Technology's (JST) maintenance of an industry-university cooperation development platform to accelerate the promotion of robotics technologies and ventures (Nirmala, 2016).[21]

Institutional support. Coinciding with the renewed growth of robotics in Japan is the nation's current bid to reclaim sector leadership. Having been overtaken by China in IR supply in recent years, Japan intends to become the world's largest society supported by robots through the promotion of both SRs and IRs (Yamasaki, 2016). In 2015, Japan launched its Robot Revolution Initiative, a public-private programme to expand the country's robotics capabilities and global footprint, and increase social acceptance of robots in the domestic market (METI, 2015). The private sector is expected to invest the required JPY100 billion (around USD 838.08 million or 740.71 million EUR[22]) funding while the public sector will be responsible for policy and regulatory reforms (METI, 2015a). In addition, the Japanese government is committing around JPY 26 trillion (around USD 229.44 billion or EUR 203.38 billion[23]) to develop related technologies such as AI and Big Data analysis and cyber-security systems (JETRO, 2016).

Demand-side trends. Apart from the needs of its factories, demand for robots and increased automation in Japan originates from various demographic challenges, including among other things, falling birth rates, ageing population and declining workforce productivity. However, Japan's problems are more severe relative to its peers: its population is expected to shrink by 30 million in the next 35 years and its over-65 population is expected to rise to a 40% share by 2025 (Kemburi, 2016). Thus, particular emphasis on SR developments for medical and nursing care (2015, EU-Japan Centre for Industrial Cooperation). On-going projects listed in the Japan Robot Association (JARA) confirm these observations as several projects are focused on medical care (e.g. Project to Promote the Development and Introduction of Robotic Devices for Nursing Care, Innovative Cybernetic System for a ZERO intensive nursing-care society, and Tough Robotics Challenge) (JARA, 2016).

[21] Selected current Japanese robot projects are listed in Table 3.

[22] FX rate on 10 February, 2015 (publication date) was 1 USD = 119.32 JPY; 1 USD = 0.88382 EUR (via exchange-rates.org).

[23] FX rate on 18 February, 2016 (publication date) was 1 USD = 113.32 JPY; 1 USD = 0.88643 EUR (via exchange-rates.org).

Table 3.8 Select existing Japanese robot projects

Project Name	Project Summary	Cost	Start	End
Project to Promote the Development and Introduction of Robotic Devices for Nursing Care	Development of assistive robotics for nursing care to reduce caregivers' burden in providing elderly care.	NA	JFY 2013	JFY 2017
Innovative Cybernetic System for a ZERO intensive nursing-care society	Development of cybernetic systems that combines the brain-nerve-muscular system, robots, and other devices to improve/assist humans who would otherwise require intensive nursing-care .	NA	NA	NA
Tough Robotics Challenge	Development of the fundamental technologies for outdoor robots, thereby leading to the development of autonomous robots for disaster response.	NA	NA	NA

Source: JARA, 2017

Apart from medical care, Japan, through the Robot Revolution Initiative, has also identified four (out of a total of 5) other high-growth robotics sub-sectors: these include 1) manufacturing; 2) services; 3) infrastructure and disaster response; and 4) agriculture (METI, 2015a). By 2020, Japan aims to achieve the following: a 25% increase in the rate of utilization of robots in large manufacturing (10% for SMEs), a 30% increase in use of robots in services (particularly, in picking, screening and checking purposes), increased societal awareness regarding robots for medical care, a 30% increase in adoption of infrastructure robots and the introduction of around 20 robot variants for agriculture (METI, 2015b).

To stimulate interest in robotics, the Japanese government is planning a Robot Olympics alongside the 2020 summer Olympic games, which will feature competitions and exhibits that involve a variety of machines such as humanoid robots and IRs (Phys.org, 2016).

Japanese firms. The private sector includes a wide variety of firms that are market leaders or specialists in industrial applications. These include: FANUC, Kawasaki Heavy Industries, Toyota Motor Corporation, Panasonic Corporation, Honda Motor Co. Ltd., Fuji Heavy Industries Ltd., ZMP Inc., Yamaha Motor Co. Ltd. Among others (EU-Japan Centre for Industrial Cooperation, 2015). The successful cases are also the top-three Japanese robotics firms by installed base.[24]

3.3.4 Korea

Overview. South Korea is an important robotics market and the second-largest by sales in 2015 (IFR, 2016c). IFR (2016c) states that 2015 performance is equivalent to around a 30% to 35% increase on 2014 values. South Korea has the highest robot density in general

[24] A more comprehensive list of Japanese robotics suppliers is available in Appendix, Table III.3

industry, at around 411 robots per 10,000 employees (for IRs alone, the number is higher at 531 robots per 10,000 employees). However, analysts have noted that South Korea does not have any sector-leading firms and it is lagging behind the US, Europe and Japan in technological innovation (Jae-Kyoung, 2016; Prakash, 2016; Kyung, 2017).

Industry and technical support. South Korea has several industry groups and associations that provide technical and market support including the Korea Robotics Society, the Korea Institute for Robot Industry Advancement, the Korea Association of Robot Industry, and the Institute of Control, Robotics, and Systems (Edwards, 2016). Numerous Korean research institutes have had successes in robotics throughout the years: Centre of Intelligent Robotics at the Korean Institute of Science and Technology's development of the household service robot CIROS, the Korean Institute of Ocean Science and Technology's half-ton maritime robot Crabster (CR200), and the Korea Advanced Institute of Science and Technology's maritime robotics project on coastal preservation (Edwards, 2014).

Moreover, the sector enjoys an active academic and research base that is engaged in expanding robotics applications. Some examples include the long-standing efforts of Korea University's Intelligent Robotics Laboratory (IRL), Chonnam National University's investigation into robotics technologies for cancer and intravascular treatments, and the collaborative work of various Korean universities (e.g. Korea University, Pohang University of Science and Technology, Seoul National University, Sogang University, and Sungkyukwan University) on AI (Edwards, 2014; Hyun-chae, 2016).

Institutional support. South Korea has been active in the robotics sector since 2012 when national government pledged around USD 316 million investment. In 2014, the Korean government, through the Ministry of Trade, Industry and Energy (MOTIE), made an additional 2.7 billion USD commitment for the development of advanced robotics (MOTIE, 2014).

The latest institutional assistance to the sector has come from an additional public commitment of around USD 450 million (or approximately EUR 400 million) (Yonhap News Agency, 2016). The Yonhap News Agency (2016) stated that both the public and private sectors would will spend around 350 billion KRW to localize key fundamental robotics technologies, with more than 100 billion KRW to be poured into corporate research centres. In addition, the Korean MOTIE is allocating USD 13.5 million (approx. EUR 12 million) for humanoid robotics R&D and necessary workforce development until 2020, and around EUR 18 million to 24 million (USD 20.25 million to 27 million) for the development of grassroots research up to 2022 (Hyong, 2017).

The latest investment stems from the Korean government's belief that most widely used SRs in country's market are vacuum robots for the household, medical and agricultural sectors (Van Boom, 2016; Yonhap News Agency, 2016). The Korean MOTIE aims that through the programme, Joint Robot Industry Development Initiative, it will help expand the country's demand robotics base through market creation and system maintenance (Hyong, 2017). Hyong (2017) states that the agency has identified four high-growth sub-sectors in which government intends to launch 90 projects by 2020: medical and rehabilitation use, unmanned robotics, social works and security. In the near-term, MOTIE will sponsor the introduction of 5-10 robots in National Rehabilitation Centres and 10-15 robots for assistive roles in general hospitals. By 2018, the agency will introduce 10 social robots in local post offices and 5 surgical robots in national hospitals (Hyong, 2017).

Firm-level information. The Korean private sector is similarly active. Korean conglomerates are involved in various sponsorships related to robotics research. In 2015, Samsung Electronics made a USD100-million investment in an R&D laboratory focused on drones, robotics, 3D printing and virtual reality (Robotics Business Review, 2016). Another case is Korean conglomerate Hyundai Heavy Industries' investments in medical SRs, with several robot deployments in various medical centres across Korea (Chougule, 2016). Korean SMEs, through government sponsorships, are producing several robot products for various applications including education, agriculture, medical rehabilitation, national defence, culture, manufacturing, environment, home services and parts, and security (Korean Institute for Robot Industry Advancement, 2017).

3.3.5 Europe

Europe has always been interested in pushing the technological frontier and its experience with robotics is another case in point. European experience with automated machines dates back to the 1970s; since then, the region has developed considerable technical and commercial competence across the growing science of robotics (Forge & Blackman, 2010). Recent IFR statistics (2016) confirm the continued relevance of Europe in robotics: the second-largest regional market posted a 10% increase in sales to 50,100 units in 2015 and it continues to have the highest robot density among all macro-regions at 92 units.

However, a number of factors are threatening European competitiveness: automation adoption remains uneven at country level including the emergence of East Asian countries (China, Japan, and South Korea) in the global robotics landscape, and the rapid expansion and development of the overall sector (IFR, 2016).

In 2014, the EU included robotics as a key research focus in its Horizon 2020 programme, a 7-year 80 billion-EUR initiative that is Europe’s primary mechanism for reinvigorating research and innovation in emerging technologies and contemporary societal challenges (The EU Framework Programme for Research and Innovation, 2014). This programme is expected to attract participation and financial contribution from universities, research institutions and the private sector (The EU Framework Programme for Research and Innovation, 2016).

Provision for robotics research is included in the Leadership in Enabling and Industrial Technologies (LEIT) priority, which is expected to receive 22% of the total funding (Juretski, 2014). Apart from the funding amount, Juretski (2014) describes other innovations introduced in Horizon 2020 (which will directly affect the dynamics of robotics R&D activities within the programme) that include the promotion of pre-commercial procurement (PCP) and public procurement of innovation (PPI).

A prominent Horizon 2020 project is EU SPARC – The Partnership for Robotics in Europe, a contractual partnership between the Commission and the euRobotics AISBL (Association Internationale Sans But Lucratif), a non-profit association for private and academic stakeholders in European robotics (euRobotics, 2017). With EUR 700 million funding until 2020, SPARC is the largest civilian robotics programme in the world; it includes over 180 member organizations from Europe to strategically position the region in the global robotics space (EU SPARC, 2017).

Another notable robotics-related project is the ‘Factories of the Future’ initiative, another public-private partnership between the European Commission and the European Factories of the Future Research Association (EFFRA), a non-profit, industry-driven association that seeks to promote the development of advanced and sustainable production technologies (EFFRA, 2017). The ‘Factories of the Future’ programme is a EUR 1.15 billion partnership that intends to realize the EU’s objective of digitizing and advancing the manufacturing production process (EFFRA, 2017).

3.3.5.1 Germany

Overview. Germany is a manufacturing powerhouse and a prominent player in the robotics industry. The sector is characterized by stable networks between OEMs,[25] lead suppliers, and notable SMEs (GTAI, 2017). Germany has globally-recognized strengths in the development of industrial robots, particularly in machine vision technologies and human-robot collaboration development (GTAI, 2017).

Industry and technical support. Germany has several robotics and industrial automation clusters including: 1) the Automation Valley Northern Bavaria cluster, 2) it's OWL – Intelligente Technische Systeme OstWestfalenLippe and 3) Silicon Saxony e.V (GTAI, 2017). The Automation Valley Northern Bavaria cluster is a vast network of companies and research institutions from a broad range of industries that include the mechanical engineering company Shaeffler-Gruppe, the IT service provider Datev, the sporting goods manufacturer Adidas and public research institutions such as the Fraunhofer Institute and the University of Bayreuth (Invest in Bavaria, 2015). The OWL cluster is a technology network of 180 businesses, universities, research institutes and organization whose purpose is advancement of mechatronics to intelligent technical systems; it is working currently on 46 applied research projects with funding of 100 million EUR (it's OWL, 2017). Silicon Saxony is a 300-strong network of semiconductor, electronics, microsystems and software stakeholders (Silicon Saxony, 2017). The cluster's current activities involve investigations in advanced sensor applications (e.g. CPS, RFID technologies) and the latest microsystems technologies developments (Silicon Saxony, 2017; Silicon Saxony, 2017).

Germany has a strong base of academic researchers investigating varied robotics sub-fields. Examples include: 1) the Institute of Robotics and Mechatronics, which investigates developments across the entire robot development process, 2) the DFKI Robotics Innovation Centre, which focuses on robot technologies for various dangerous environments (e.g. space, underwater, etc.), and 3) the Technical University of Munich and its work on CPS and other SRs (e.g. medical robots, humanoid robots) (Edwards, 2015).

Institutional support. Industrie 4.0 is Germany's main innovation programme in advancing manufacturing through the development and convergence of key ICT and robotics technologies. Part of Germany's Action Plan High-tech strategy 2020, Industrie 4.0 started in 2013 as a collaborative effort among the nation's leading business associations BITKOM, VDMA, and ZVEI (BMWi & METI, 2016). In 2015, the German government committed approximately 500 million EUR to the programme (Temperton, 2015). Today, it is an institutional commitment (led by the German Ministries of the Economy and Research) and involves over 300 stakeholders from over 150 public and private organizations (Smit, et al., 2016; Banthien, 2017).

Demand-side trends. The country is the fifth-largest market by sales and in spite of already possessing a high robot density of 301 units per 10,000 employees, annual sales remain high (IFR, 2016c). The automotive sector is the leading client sector for German robotics while the electrical and electronics industry is the second-largest (GTAI, 2017).

[25] OEMs are often the original producers of vehicle components.

GTAI (2017) details that the metal processing and machinery, plastics and chemicals, and food industries in Germany are other major client sectors.

2016 was another record year for sales for German robotics companies, with sales reaching a new high of EUR 12.8 billion. (VDMA, 2017). VDMA statistics (2017) show that 57% of German robotics are exported, with China being the biggest market (accounting for 10%) and North America the second biggest (9%). The industry association expects that 2017 robot sales will accelerate by 7% because of increased foreign demand (Reuters, 2017).

The German robotics industry falls into three main sectors: Robotics sub-sector, Integrated Assembly Solutions (IAS) sub-sector, and Machine Vision Technologies sub-sector (GTAI, 2017). 2016 robot sales suggest that while all sub-sectors posted increasing sales, IAS remains the largest (VDMA, 2017).

3.3.5.2 France

Overview. France is considered an important robotics market in Europe, and has embraced increased automation in its production process (even though its install base and sector performance remain low relative to other developed regions). 2016 IFR statistics indicate that France posted an increase in robot sales, with 3,045 units in 2015.

Industry and technical support. Sector support is available through industry associations, such as the SYROBO Group, and industry research organizations and platforms, such as the Technical Centre for Mechanical Industry, the French Robotics Research Group, and the French National Robotics platform. The SYROBO Group is a robotics industry association that represents the interests of private stakeholders in service robotics (SYMOP, 2017). The Technical Centre for the Mechanical Industry is a private-led institution that facilitates interaction between academia and various industries regarding the adoption and development of advanced manufacturing technologies (CETIM, 2017). The French Robotics Research Group and the French National Robotics platform are networks that foster cooperation and collaboration among academics, researchers and engineers (Business France, 2017; FEMTO-ST, 2017).

Institutional support. Since 2013, France has shown strong commitment to developing emerging technologies (including robotics) through various levels of institutional support, the most prominent being the 'New Face of Industry in France' programme (Ministère de l'economie, 2015). The reported support for the robotics and related technologies was around EUR 1.2 billion (Ministère de l'economie, 2015). In 2015, the French reindustrialization plan entered its second phase - the 'Industry of the Future' programme. The current programme is expected to build on the 'Factory of the Future' plan through further investments in key advanced manufacturing technologies (among others, additive manufacturing and production digitization). Particular to robotics, the programme provides an additional EUR 2.1 billion financial support until 2017 (Ministère de l'economie, 2015). Around the same time, a collaborative platform, Alliance Industrie du Futur, for firms and academic and technological partners was formed to help realize the programme's goals (Alliance Industrie du Futur, 2015)

Firm-level information. France is home to a number of notable robotics companies: humanoid robot developer Aldebaran Robotics (Softbank Robotics), French UAV copter provider Infotron, and surgical robots firm Medtech (Tobe, 2014; Medtech, 2017; Softbank Robotics, 2017). Apart from these, despite perceptions regarding the rigidity of its labour regulations, France already has an emerging startups scene that enjoys the healthy optimism of its stakeholders (Cellan-Jones, 2017).

Contemporary issues. Despite the positive developments in the French robotics landscape, there are concerns that there is underrepresentation of these systems because of social perception and risk aversion (Pape, 2017). Moreover, there were doubts regarding proposals from the French socialist government to tax robots. Observers believe that if this persists it could disadvantage France because it is likely to be ineffective for arresting the consequent technological unemployment among low-skilled laborers through automation and would discourage firms from innovating (Bershidsky, 2017).

3.3.5.3 United Kingdom

Overview. The UK is a promising robotics market, although there is notable underinvestment in the sector relative to the other industrialized nations. 2016 IFR statistics suggest that there is a sustained decrease in sector performance in UK: 2015 robot sales decreased to 1,645 units.

Industry and technical support. Institutional support is available mostly through the industry associations, such as the British Automation & Robot Association (BARA), and special interest networks, such as the UK Robotics & Autonomous Systems (UK-RAS) Network. BARA is one of the most prominent robotics association in England and draws membership from both robotics and related industries (e.g. system integrators, components and ancillary parts) (BARA, 2017). The UK-RAS Network is an academe-led network of universities, companies and public research institutions that aims to promote the development of UK robotics' capabilities (UK-RAS Network, 2017a). The UK-RAS Network is responsible for the annual UK Robotics Week and for several competitions related to various robot applications (e.g. surgery robotics, social care robotics, robots for educational purposes) (UK-RAS Network, 2017b).

Furthermore, there are robotics-dedicated research institutions in British universities. Examples include the Centre for Robotics Research (CORE) in King's College, the Bristol Robotics Laboratory (BRL) of the University of Bristol and the University of West England, the Robot Vision Group at the Imperial College London, the Robotics Research Group in the University of Oxford, the Centre for Automation and Robotics Research at Sheffield Hallam University, and the Robotics and Intelligent Systems Lab at Plymouth University (Robotics Business Review, 2014). Some facilities investigate various robotics sub-fields, such as in CORE and BRL, while others are more specialized, such as in The Robot Vision Group (The Robot Vision Group, 2014; BRL, 2017; CORE, 2017).

Institutional support. Since 2015, the British government has recognized the technology's potential for improving British manufacturing productivity and has committed to building the country's research and industry capabilities (Department for Business, Innovation & Skills, 2015). Institutional support is mostly channelled through the Engineering and Physical Sciences Research Council (EPSRC), the 500 million GBP-funded UK innovation agency Technology Strategy Board, and the recently-formed Leadership

Council in Robotics and Autonomous Systems (DBIS, 2015; Westlake, 2015). 2016 EPSRC-sponsored investigations in robotics applications in manufacturing amounted to approximately GBP 350 million (around EUR 410.66 million[26]) and involved various universities across Britain (among others, University of Cambridge, Imperial College London, University of Leeds, University of Manchester) (UK-RAS Network, 2016). Furthermore, the UK-RAS Network (2016) identifies seven research centres ('Catapult Centres') that enable companies to access equipment, expertise and information needed to develop and commercialize ideas and innovations. More recently, PM Theresa May's government announced a GBP 4.7 billion Industrial Strategy 2020, in which robotics and related technologies are a key focus (HM Government, 2017).

Nevertheless, observers are cautious about Britain's renewed enthusiasm towards robotics; the country traditionally has been slow to commercialize its research and sustaining sector growth requires converting the potential demand base into innovation partners (Williams, 2015; Westlake, 2015).

Demand-side trends. Despite remaining a key global manufacturing nation and despite various investments in production automation, the UK does not participate in the design, development and manufacturing of key robotics technologies (Cheeseman, 2017). Industry observers note that outside of the country's automotive sector, there is notable risk aversion to robot adoption in manufacturing processes (Tovey, 2016). Some attribute this conservatism to certain aspects of British manufacturing experience, such as British financial institutions' preference for short-term returns on loans and a technical skills gap related to robotics technologies (Hadall & Wilson, 2017). Moreover, contemporary conversations surrounding the subject remains centre on robots' perceived negative consequences for employment (Williams, 2016; Faig, 2017)

Recent reports suggest that the UK is making significant progress towards increased automation. Around 58% of general British manufacturing have made automation-related investments and reaped clear benefits (Barclays PLC, 2015). Among Scottish manufacturers, the figure is higher: 72% have reported investments in production automation (Wilcock, 2015).

Firm-level information. Despite the situation in British robotics, there are a number of notable UK-based emerging robotics companies (particularly, in medical care applications) and startups. Renishaw PLC is a Gloucestershire-based firm with expertise in robotics surgery – its neuro-robotic device, called Neuromate, is used for various surgical procedures in several countries (e.g. UK, France Germany) (Demaitre, 2016). Another example is Cambridge Medical Robotics, whose work is focused on developing next-generation universal robotic systems for minimally invasive surgery (Cambridge Medical Robotics, 2017). Meanwhile, UK-based robotics startups have varied focuses, but most trace their beginnings to a university: examples include bio-mechanics developer Animal Dynamics (Oxford University), educational bi-pedal robot producer Robotical (University of

[26] FX rate on 13 January, 2017 (date of report publication) was 1 GBP = 1.1733 EUR (via exchangerates.org.uk).

Edinburgh), and companion and assistive robotic systems developer Consequential Robotics (University of Sheffield) (Macaulay, 2017).

3.3.5.4 Italy

Italy is a key robotics market, the second-largest in Europe after Germany and the seventh-largest in the world (IFR, 2016c). In the context of European production of robots applied to automotive manufacturing, and due to the specific contribution of Piemonte, Italy is the top ranked manufacturer. The latest IFR (2016) statistics show that Italy continued its increasing robot intake, with a 7% increase in 2015 sales and +1.1% increase in revenues. Moreover, IFR statistics from the Italian Trade Agency (2016) suggest that the country has the second-highest robot density in Europe. After a period of crisis between 2011 and 2013, the sector started to grow again reaching a dominant position in the global supply of robots. In 2015, in Europe, there was a 10% growth in total production with 20,000 robots produced in Germany, 6,700 in Italy and 3,800 in Spain. This represents significant growth, but small compared to China which produces 70,000 robots annually (IFR, 2016c).

The results for the Italian robotics sector are confirmed if we split break down by the supply chain. According to data on Italian robotics for 2016 provided by UCIMU – the research and corporate culture centre, there have been stable increases in both exports and internal sales. Consumption of robots in Italy registered a 1.7% increase, accounting for EUR 676 million (UCIMU, 2017).

Table 3.9 Italian robotics sector (EUR million)

	2015	2016	% of increase
Revenue	528	534	1,1
Export	188	190	1,1
Local market	340	344	1,2
Import	325	332	2,2
Trade balance	137	142	/

Source: Ucimu (2017)

Italy's heavy adoption of and strong interest in robotics comes as no surprise when set against its manufacturing capabilities and history of technological competence. Italy has a strong industrial machinery and related products sector – 2016 statistics demonstrate the country's continued relevance in the global industrial landscape and its industry's export-based orientation (UCIMU, 2017). However, there are only a few large industrial and ICT firms in the sector; Italian manufacturing is founded deeply on small and medium enterprises (Italian Ministry of Economic Development, 2017).

Industry support and representation are available through industry trade associations, such as the UCIMU-Sistemi per Produrre. UCIMU is the official interest group for the domestic machine tool, robots, automation systems and ancillary products manufacturers (UCIMU, 2017). Current membership statistics suggest that the association represents over 200 companies accounting for over 70% of the selected industries (UCIMU, 2017).

UCIMU splits Italian firms working in robotics into three macro-categories according to revenue: large firms with revenues higher than EUR 5 million; medium sized firms with revenues of between EUR 2.5 million and 5 million; and small sized firms with less than EUR 2.5 million revenue. In general terms, large firms are prominent and account for 75% of Italian robotics production.

Table 3.10 Italian firms in robotics by class of revenue.

Revenue (bln of Euro)	2013	2014	2015	2016
<2,5	16%	13,4%	6,7%	8,3%
2,5-5.0	11,1%	13,3%	20,0%	16,7%
>5.0	72,2%	73,3%	73,3%	75,0%
Tot.	100,0%	100,0%	100,0%	100,0%

Source: Ucimu (2017)

Analysing the whole Italian production in robotics, in 2016 there were 114,873 robots operating, with an annual increment on 2015 of 6,823 units (UCIMU). 75,078 units (65% of total robots production) are engaged in the manipulation activities, followed by welding with 33,503 units (19.6%), followed by assembly robots with 7,466 units (6.5%), cute robots with 3,481 units (3.0%), and other robots (5.5%).

Table 3.11 Type, units and % of robots in Italian supply chain, 2016

Type	Unit	%
Handling	75.078	65,4
Welding	33.503	19,6
Assembly	7.466	6,5
Cute	3.481	3,0
Other	6.345	5,5
Tot.	114.873	100,0

Source: Ucimu (2017)

Table 3.12 Main firms competing in robotics in Italy, their location and the kind of robots they produce (excluding Piemonte)

Name	Region	Robot production
ABB	Lombardia	Assembly Robot, Welding Robot, Robot for didactic, Others
AMADA ITALIA s.r.l	Emilia Romagna	Welding Robots, Others
AUOTOMATOR INTERNATIONAL s.r.l	Lombardia	Press automation
BUCCI AUTOMATION s.p.a	Emilia Romagna	Cartesian coordinate Robot
CB FERRARI A SOCIO UNICO s.r.l	Lombardia	Cartesian coordinate Robot
CESMA INTERNATIONAL s.r.l	Lombardia	Welding Robot
COSBERG s.p.a	Lombardia	Assembly Robot
FARINA PRESSE s.r.l CON SOCIO	Lombardia	Cartesian coordinate Robot
FICEP s.p.a	Lombardia	Cartesian coordinate Robot
HIWIN s.r.l	Lombardia	Measurement Robot
INTER.CAR s.n.c DI GAITO	Campania	Cartesian coordinate Robot
NUOVA C.M.M s.r.l	Veneto	Welding Robot, Others
OPPENT	Lombardia	Others
ROLLON s.p.a	Lombardia	Cartesian coordinate Robot
SIR. s.p.a	Emilia Romagna	Cartesian, Cylindrical and polar coordinate Robot, Welding Robot, Mounting Robot, Robot for didactic
SPERONI s.p.a	Lombardia	Measurement Robot
STAR s.r.l	Lazio	Welding Robot, Assembly Robot, Cartesian coordinate Robot

Name	Region	Robot production
TIESSE ROBOT s.p.a	Lombardia	Assembly Robot, Welding Robot, Robot for didactic, Cartesian coordinate Robot, Others
ZUCCHETTI CENTRO SISTEMI	Emilia Romagna	Others

Source: UCIMU

Technical and research support is available within the high-skilled workforce located across Italy's main cities of Milan, Turin, Rome, Pisa and Genoa among others (Italian Trade Agency, 2016). For instance, the IIT (Italian Institute of Technology) in Genoa is working with the precision-motion company, Moog, Inc., towards the development of next-generation actuation and control technologies for autonomous robots (Heney, 2016).

Italy's institutional support for robotics is in the form of its National Plan, 'Industria 4.0.' Industria 4.0 is an 18-billion EUR comprehensive public-private partnership that offers the domestic industry a wide array of complementary measures (e.g. tax credits, favourable loan terms for adopters, and preferential services to SMEs) to spur investment in advanced manufacturing technologies and provide streams of financing to domestic enterprises (Italian Ministry of Economic Development, 2016a; Italian Ministry of Economic Development, 2016b). Among Industria 4.0's instruments, the most important are 'hyper-depreciation' and 'super-depreciation' – where the Italian government allows a 250% tax benefit on purchases of Industry Industria 4.0-related tangible assets, and a 140% tax benefit on the cost of Industria 4.0-related investments (PwC, 2017).

In addition, there is a notable public-led programme which is the Italian Trade Agency's 'Machines Italia' Campaign. This project, which provides an innovation platform for Italy's machinery manufacturers, aims to demonstrate the country's strengths in manufacturing, machinery, robotics and related areas (MIT Technology Review, 2017; Machines Italia, 2017).

3.3.5.5 Piemonte – Turin

Italian robotics companies are concentrated in the North of Italy. Lombardia and Piemonte account for respectively 33.4% and 25% of firms operating in robotics, Piemonte shows a higher concentration of revenues (62.8%) and employees (60%).

The industry area related to robotics present in Piemonte and, mostly, Torino, is innovative and typically is characterized by large firms. Firms such as COMAU, Olivetti, DEA, Prima and others entered the market in the 1970s and have reached a predominant role. In 2011, Istat registered 3,900 firms in mechatronics/robotics in Piemonte (1,900 in Torino), with 62,000 employees (27,000 in Torino). In the robotics sector alone (excluding mechatronics) there are 250 firms with 12,000 employees, who represent 44% of the national share. According to Istat, in 2013, Piemonte's share was around 11% of national exports in the industry, worth EUR 2.5 billion in value, including EUR 1.3 billion generated in Torino.

Table 3.13 Robotic/Mechatronic industry in Piemonte. 2011

Robotic/Mechatronic	Firms	Employees	Export (bn Euro)
Piemonte	3,900	62,000	2.500 (11% of italian export)
Turin	1,900	27,800	1.308 (5,8% of Italian export)

Source: ISTAT 2011

Table.3.14 Main robotic firms in Piemonte region.

Name	Robot production
COPROGET s.r.l	Cartesian coordinate Robot
HEXAGON METROLOGY s.p.a	Measurement Robot
KUKA ROBOTER ITALY s.p.a	Assembly Robot, Welding Robot, Robot for didactic, Measurement Robot
PRIMA INDUSTRIE s.p.a	Robot for cutting, Welding and microboring
COMAU	Welding Robot, Assembly Robot, Others
EIKAS	Welding Robot

Source: UCIMU

Piemonte regional firms have been able to create a district specialized in technologies that are related to automotive. Piemonte has developed an eco-system, including regional institutions, manufacturing industry, craft and agriculture, research centres and universities.

Since 2009, Piemonte has supported an active industrial policy to foster technological innovation. With POR FESR plans 2007-2013, the Regional Operative Programmes financed by the European Fund for Regional Development, Piemonte gave birth to innovation poles (Poli di Innovazione), which are clusters of independent firms (large, medium and small sized) together with research centres working on specific sectors and coordinated by a managing authority.

These poles group together the actors involved in the innovative process stimulating interactions, sharing of installations, knowledge and experience, contributing to the widespread of information and technologies across firms. Moreover, poles need to interpret the technological needs of firms in order to guide the region in its decisions related to research and innovation. For five years the regional programme has financed research and innovation projects, feasibility studies and services.

The MESAP pole was conceived specifically for robotics and mechatronics for advanced production systems. Its implementation was cross-sectoral involving shaping/plant and design/robotics, automotive, aerospace, electrical appliance, railroad, textile, print, energetic/environmental, agro-industrial, construction industry/housing sector. Three fields of research and innovation have been financed:

- smart products: mechatronic applications to consumer and industrial products;
- flex processes: mechatronics and advanced production system applications for flexibility of productive processes;
- green processes: mechatronics and advanced production system applications for energy efficiency and eco compatibility of productive processes.

Projects cover a variety of production: sensors to enlarge mechatronics applications; reduction of energetic and environmental impact of manufacturing; automated microprocessor systems; mechatronic systems for vibration control; mechatronic systems for accumulation and power management; open-source integrated environments for mechatronic applications product-process; flexible automation systems; flexible mechatronic systems for distributed printing; monitoring and control of industrial processes; MEMS (Microelectromechanical Systems) adaptive testing; automotive and mechatronic systems; and components product development and manufacturing.

In the pole, 36 projects have been financed, totalling EUR 41.53 million in investments and a contribution of EUR 21.45 million. MESAP has 170 members, 2 universities, 9 research centres, 129 PMI, 30 large firms and 14 industrial sectors; the management is entrusted to Centro Servizi Industrie Srl, a service company of the industrial union of Turin.

POR FESR 2014/2020 has further boosted Piemonte’s investments in mechatronics and robotics, giving innovation poles continuity. In the new funding programme, the Piemonte region shows a unity of purpose with local private actors offering support to enforce the smart specialization of manufacturing and, particularly, of robotics and advanced production systems. Measures published for those sectors refers to fundamental actions to achieve the following objectives:

- building a technologic platform on advanced production systems which can compete at global level;
- strengthening the role of innovation poles making them regional agencies for innovation
- facilitating the update of productive machines and plants
- increasing the presence on markets of firms belonging to the most relevant supply chains of Piemonte.

3.4 Additive manufacturing (AM)

AM is the official industry standard term (ASTM F2792) concerning the process of joining materials to make objects from 3D model data (Wohlers Associates, 2010). 3D printing is the most popular term.

According to EY (2016) a growing number of global industrial firms have acquired experience on AM and consider it strategic for their growth, but most companies still have no experience with 3DP. The major obstacle to adoption is the high degree of uncertainty on how this technology can be applied.

Depending on the degree of confidence in the possibilities of 3DP for the productive process, manufacturing companies consider 3DP simply as: i) an additional approach to fabrication; ii) a hybrid technology integrating the existing processes; iii) a technology that will replace actual manufacturing systems in most of the industries.

AM includes seven main subtechnologies (Conner et al., 2014): material extrusion, vat photopolymerization, binder jetting, powder bed fusion, directed energy deposition, material jetting, sheet lamination. The materials adopted are mainly metals and polymers, but ceramic is expanding. Among companies already using **metal 3DP**, **aerospace and automotive** companies are at the top of the list.

AM is based on the concept of **rapid prototyping** in areas of production characterized by low volume, low complexity and low levels of product customization. Printed prototypes are more cost effective and can be produced more quickly and used for design and marketing purposes, in particular.

Beyond prototyping, operational efficiency can be achieved also through direct manufacturing of particular types of items. In particular, as suggested by Conner et al. (2014), AM can be effective for **complex products** production and **customized manufacturing** in both mass and artisanal production. For example, serial 3DP is applied to lightweight parts and functionally integrated components, bringing value to aerospace companies and automotives (sports cars).

Typical limitations to adoption are cost, technology and business organization. AM is still expensive because of the price of systems, materials and related services, thus some companies are not unwilling to invest without a clear strategic vision of the actual applications. Technological limitations are related to building envelope and product sizes, constraints in the use of materials and multi-materials and careful control over product quality. AM sets demanding business challenges related to lack of in-house expertise, management of IP issues and integration with the status-quo in the productive chain.

According to Wohlers (2017), 97 manufacturers produced and sold industrial AM systems in 2016. This is up from 62 companies in 2015 and 49 in 2014. Growth in 3D printer sales slowed in 2016, due to a slowdown at **3D Systems** and **Stratasys**, the two industry leaders by revenue. Together, they represent $1.31 billion (21.7%) of the **$6.063 billion** AM industry. The 3DP market is expected to grow by about 25% annually until 2020 (EY, 2016) – resulting in a total market value in that year of US$12.1 billion. Market volumes have increased from $1.5 billion in 2011 to $4.2 billion in 2015. In worldwide **revenues in 2016** the AM industry grew by only 17.4%, down from 25.9% the previous year.

Companies interested in entering 3DP production have two main options. The can purchase from systems manufacturers and build an in-house system, or rely on service providers for the supply of 3D printed items.

System manufacturers are the masters in the 3DP value chain (Figure 3.1) since they can supply final clients directly or establish business to business relationships with manufacturing companies and service providers. They account for about 55% of the total 3DP market, while service providers represent around 25%. The most important systems manufacturers are Stratasys, 3D Systems, EOS, Concept Laser, SLM Solutions, ExOne and Ultimaker.

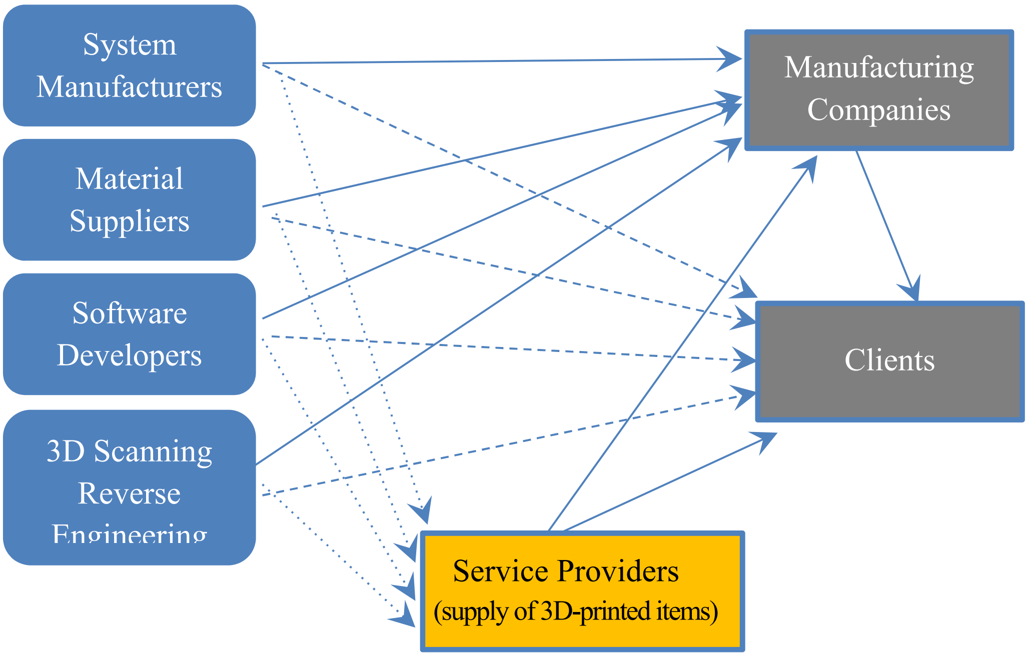
Material Suppliers provide the different materials used in the production of items. The most complex and expensive segment is metals related.

Software Developers typically belong to traditional software houses or international technological groups which use this channel to explore the 3DP market.

3D Scanning companies are a small group of players who design existing products for testing or performance purposes.

As already mentioned, the second relevant segment of players is *service providers*, which print objects professionally with endless customization. Both are clients of the previously mentioned suppliers and also supply industrial companies and other clients (Fig.3.1)

Figure 3.1 Value chain in the 3dp market.



Source: EY (2015)

3DP systems are divided into two major segments: personal/desktop printers and professional/industrial printers. The former is a quite competitive and relatively contestable market (Table 3.15). In the latter, Stratasys, 3D Systems and EOS accounted for about 70% of market share in 2015. In 2016, this side of the market was marked by decreased sales from the industry leaders, Stratasys and 3D Systems (USA), which reached a peak in 2014, while EOS (Germany) increased its share thanks to its growing metals business (Table 3.16). Both American companies were weakened by the market entry of two major multinational businesses. GE has embarked on a strategy of acquisition and established the GE Additive.

HP entered into the market in 2016 with the shipment of their first Multi Jet Fusion printers. In 2015, more than 76% of industrial investors were already in the 3DP business, reflecting the strong consolidation pressure in the market. This consolidation trend will continue as large systems manufactures adopt new technologies by acquiring smaller, specialized players.

Table 3.15 Top 5 Vendor 3D Printer Market Share by Unit Volumes and Printer Revenues, Global Personal/Desktop Printers 2016 https://www.contextworld.com/3d-printing-research-update-12-apr-2017

2016 Rank by Units	Company	2016 Units	2016 Share by Units
1	XYZprinting	80.902	25%
2	Monoprice	27.944	9%
3	Ultimaker	24.058	8%
4	M3D	21.656	7%
5	FlashForge	17.321	5%

2016 Rank by Units	Company	2016 Revenue	2016 Share by Unit Revenue
1	Ultimaker	$44.0M	13%
2	XYZprinting	$39.7M	12%
3	Stratasys/makerbot	$38.9M	12%
4	Formlabs	$30.3M	9%
5	Aleph Objects	$17.7M	6%

Table 3.16 Top 5 Vendor 3D Printer Market by Revenue from Industrial/Professional Machines shipped 2016

2016 Rank	Company	Revenues from Machines Sold	2016 Global Revenue Share	Y/Y Change
1	Stratasys	$ 427M	34%	-5%
2	EOS	$ 210M	17%	15%
3	3D Systems	$ 144M	11%	-19%
4	SLM Solutions	$ 76M	6%	21%
5	Concept Laser	$ 66M	5%	41%

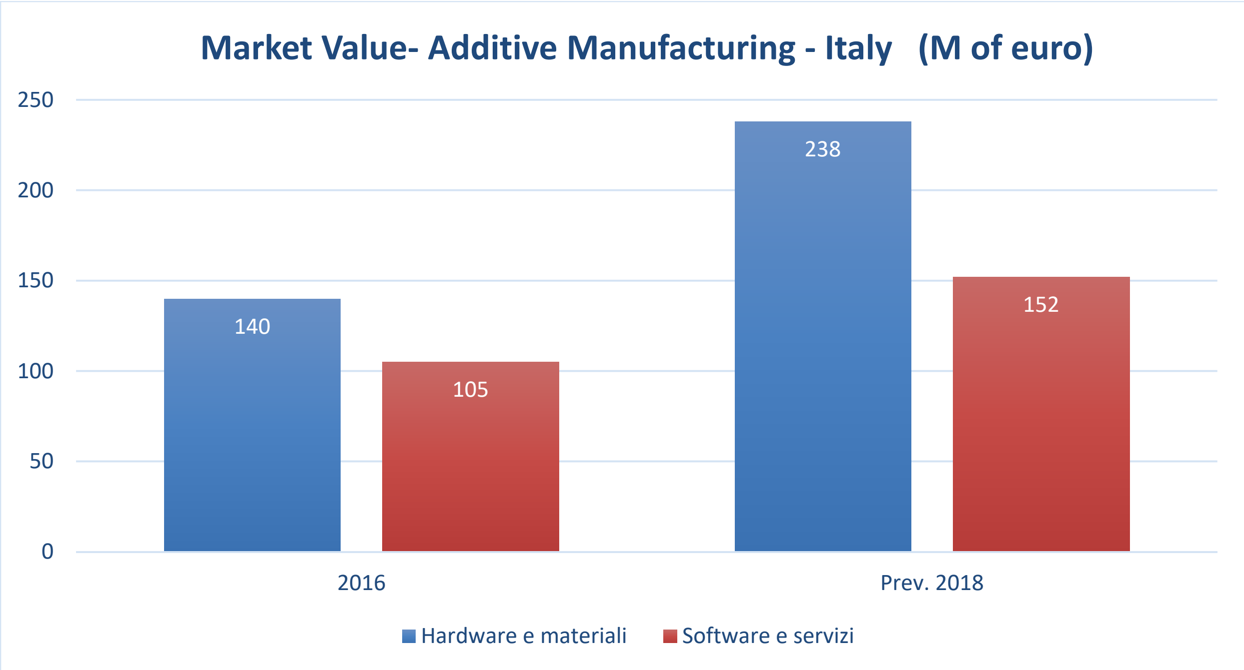
The market for service providers is led by two players: Materialise96 and ProtoLabs (for which 3DP accounts for around 10% of their revenue). Nevertheless, the service provider market is characterized by a large number of small service providers and start-ups.

It not possible to say whether companies prefer in-house systems or service providers. Given the high cost of investment, on-demand production seems to be a growing trend. Extreme customization pushes companies to select locations near end-use markets, and to open new opportunities to return manufacturing to Western countries (re-shoring).

3.4.1 Italy and Piemonte

AM is one of the sectors set to grow the most in the near future in Italy. Excluding public administration, healthcare and research centres, the market value of 3D printing in the industry sector stands at EUR 245 million (about 3.5% of the world market). Of this, EUR 140 million are from hardware and materials and EUR 105 million are from software and services. Forecasts between 2016 and 2018 saw an increase to EUR 390 million in 2018. (Netconsulting cube & Cherry Consulting; 2017)

Table 3.17 AM value in Italy. Excluding PA, healthcare e research centre



Source: Netconsulting cube e Cherry consulting, 2017

The technologies linked to 3D printing offer a multitude of solutions in various fields and, particularly, in areas of Italian excellence such as automotive, spacecraft, biomedical and packaging. 3D printers have the ability to create highly complex projects and structures, greatly reducing costs and time-out in different business segments.

For example, AM technologies can reduce the time needed to enter the market because of their ability to implement R&D projects faster than traditional technologies.

Nonetheless, 3D printing is able to produce significant benefits in the various production steps, such as greater agility in design, reduced production times, increased production efficiency and, especially, a major reduction in production chain errors.

The advantages of add-in manufacturing technologies can be summarized as:

- possibility of a wider range of alloys than traditional technologies
- possibility of using materials that are difficult to use in traditional casting processes
- production of components and objects of any shape
- reduction in production costs
- reduction in time spent on production processes
- weight reduction through topological optimization (simulation of software production), which also means less material consumption
- reduction in the number of moulds expected
- integration of multiple components into one part
- mechanical properties superior to fusion
- significant reduction in percentage of waste compared to traditional merger.

One of the significant aspects related to Italian excellence is the possibility to create highly complex structures in one mould thanks to additive technologies. So far these structures have been produced as separate parts and assembled at a later stage. This feature is particularly valued by the automotive and aerospace sectors, where complex components can be realized by reducing the weight of the structures. Also, in the field of design, it is possible to obtain more sophisticated bends otherwise unattainable using traditional technologies.

The entire Made in Italy sector of excellence is able to renew and innovate in different fields to face the challenges posed by new technologies, in a country where adoption of AM focuses mainly on the prototyping and production of components with important handicraft and customization features. Table 3.18 presents estimates of the main areas of application of additive manufacturing in the Italian sector in 2014.

Table 3.18 Estimates of main application area of AM in Italy

Industry	2014 (%)	2014 (Revenue in mln of Euro)
Aerospace	17.7	23.1
Industrial	17.7	23.1
Healthcare	15.5	20.1
Automotive	11.1	14.4
Jewellery	11.1	14.4
Energy	4.4	5.7
Others	22.5	29.2
Total		130

Source: Cherry consulting

In addition to the production phase, the benefits of AM can be found in the design, prototyping, logistics and post-sales assistance phases. In other words, additive technology is able to generate both product and process innovations, redefining the entire industry supply chain. Due to the relevant role of 3D printing technologies in automotives and in the field of space technology, production time is reduced dramatically. For example, in automotive production, traditional technology requires some 36-40 months while AM times can be as little as 18 months (Confindustria Centre).

Piemonte is a leading region for the number of companies using 3D printing technology. AM in Piemonte represents a technological excellence, thanks mostly to Avio Aero (GE Aviation Group), a leader firm with plants in Rivalta di Torino and in Cameri (Novara). Avio Aero is linked to an important chain of companies specialized in the production of hi-tech components for aerospace, energy and racing. Its headquarters was established in Cameri in 2013, representing, with its 60 3D printing machines, one of the world's most highly-accredited manufacturing plants. The goal of the pole is to become a leader firm in aeronautical industrial production for specific segments such as lighter structures to reduce fuel consumption, emissions and production times.

However, 3D printing features confirm Piemonte's as the leading actor also in design, which is one of the areas where, historically, it has played an important role; now 3D printing is enabling direct transfer of CAD graphics to prototypes and original productions, cutting out numerous assembly phases.

Table 3.19 lists the major companies in Piemonte involved either in manufacturing or in segments which are close or complementary to AM technology.

Table 3.19 Main competitors in AM in Piemonte region

Firms	Location	Activities/sector
Plyform composites srl.	Novara	Areonautic
3D System Italia Srl	Torino	Prototyping
Aerosoft Spa	Torino	Aeronautic
Altair Engineering Srl	Torino	Filtration and air purification
Apr Srl	Torino	Precision mechanics
Axist Srl	Torino	Dimensional testing, Coordinate Measuring machines (CMM)
Ec International France Sas	Torino	Prototyping
Esi Italia	Torino	Design and construction
Itacae Srl	Torino	CAD design
Microla Optoelecrtonics Srl	Torino	Laser marking machines
Reinshaw Spa	Torino	Metal additive manufacturing
Ridix Spa	Torino	Prototyping

Firms	Location	Activities/sector
Spring Srl	Torino	Prototyping
Avio Aero	Novara/Torino	Additive Manufacturing for Aeronautic
Prima Industrie	Torino	Laser system for industrial application, Sheet metal machinery
Ellena	Torino	Precision mechanics
Comau	Torino	Industrial automation
Prima Electro	Torino	Machine industry

3.5 Automotive Industry

The automotive in 2013 is still one of the major manufacturing industries although its pivotal role in the world economy is heterogeneous across countries. Its contribution to value added and employment in the OECD countries is relatively small, but strongly correlated to the business cycles and private consumption of most advanced economies.

Worldwide sales reached a record 88 million autos in 2016 (PwC, 2017) with record sales in the US (17.5m vehicles in 2015), while in EU 12.6 million new cars were registered well below the 18 million in 2007 (PwC, 2016). On the demand side, the Middle East and African markets are growing and emerging markets are stagnating.

Performance indicators are not encouraging: total shareholder return is 5.5% on average vs 14.8% S&P500 and 10.1% DJI; ROI is around 4% vs about 8% of the industry cost of capital (PwC, 2017).

Therefore, automotives are showing high levels of innovation related to connected, intelligent and driverless cars. In the meantime, the industry is exhibiting two major trends: increasing concentration and power of large established companies, and a long upstream and downstream value chain (Smitka and Warrian, 2017). In addition to consolidation, the rising cost of software and digital technology, safety and environmental regulation, are calling for solutions such as shared platforms, exploration of distribution channels and outsourcing of technological development (PwC, 2017)

In 2016, more than 94 million cars have been produced in 20 countries around the world, around 30% in China, followed by the US (13%), Japan (10%) and Germany (6%) (see Table 3.20). While China and USA are the biggest markets for sales, Japan and Germany are the production leaders. Their respective major carmakers, Toyota and Volkswagen, have been competing for rank leader and delivering around 10 million vehicles each. Below, we focus on carmakers, and the development of robotics technologies.

Production in Italy amounts to just over 1 million cars per year and sales of 2 million. We examine the traditional Italian car capital Piemonte. France and especially Italy and UK are large markets, but have lost most of their productive capacity.

Table 3.20 2016 Country Rankings by Production

#	Country	Cars & Trucks Production	%	Peak Year
1	China	28,118,794	30%	2016
2	USA	12,198,137	13%	1999
3	Japan	9,204,590	10%	1990
4	Germany	6,062,562	6%	2007
5	India	4,488,965	5%	2016
6	South Korea	4,228,509	4%	2011
7	Mexico	3,597,462	4%	2016
8	Spain	2,885,922	3%	2000
9	Canada	2,370,271	2%	1999
10	Brazil	2,156,356	2%	2013
11	France	2,082,000	2%	1989
12	Thailand	1,944,417	2%	2013
13	UK	1,816,622	2%	1963
14	Turkey	1,485,927	2%	2016
15	Czech	1,349,896	1%	2016
16	Russia	1,303,989	1%	2012
17	Indonesia	1,177,389	1%	2014
18	Iran	1,164,710	1%	2011
19	Italy	1,103,516	1%	1989
20	Slovakia	1,040,000	1%	2016
-	**World Total**	**94,976,569**	100%	2016

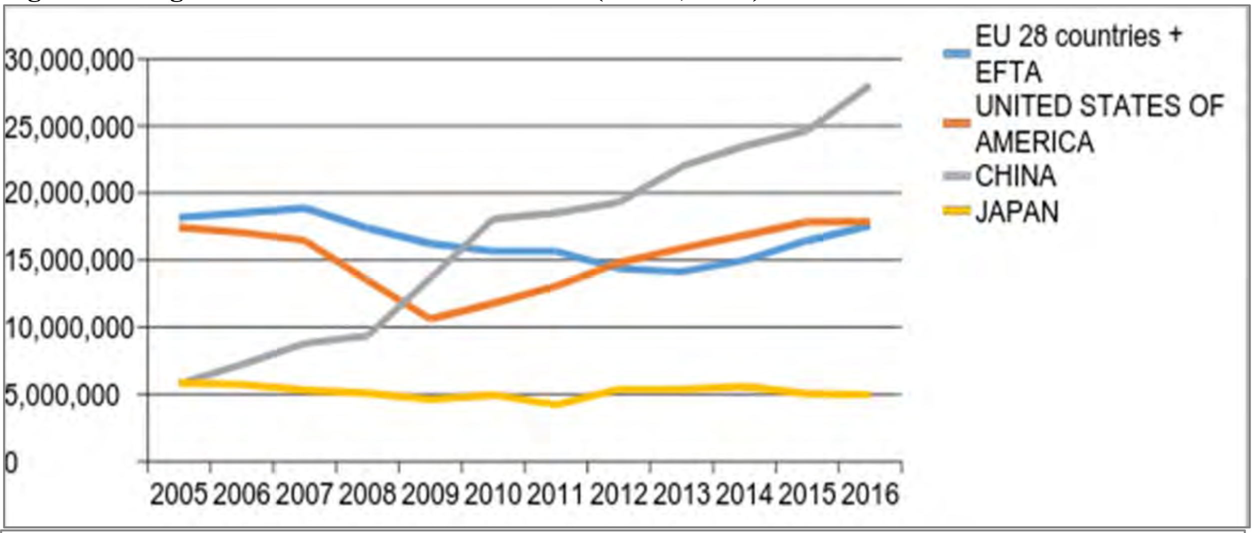
Source: OICA

Table 3.21 Manufacturers Ranking by Production (2015)

#	Manufacturer	Cars & Trucks Production	
1	Toyota group	10,083,831	JPN
2	Volkswagen group	9,872,424	GER
3	Hyundai-Kia	7,988,479	KOREA
4	General Motors	7,485,587	USA
5	Ford	6,396,369	USA
6	Nissan	5,170,074	JPN
7	Fiat Chrysler	4,865,233	ITA-USA
8	Honda	4543838	JPN
9	Suzuki	3,034,081	JPN
10	Renault	3,032,652	FRA
11	PSA Peugeot Citroen	2,982,035	FRA
12	BMW	2,279,503	GER
13	SAIC	2,260,579	CHI
14	Daimler (Mercedes-Benz)	2,134,645	GER
15	Mazda	1,5405,76	JPN
16	ChangAn	1,540,133	CHI
17	Mitsubishi	1,218,853	JPN
18	Dongfeng	1,209,296	CHI
19	BAIC	1,169,894	CHI
20	Tata	1,009,369	IND

Source: OICA

Figure 3.2 Registration or sales of new vehicles (OICA, 2017)



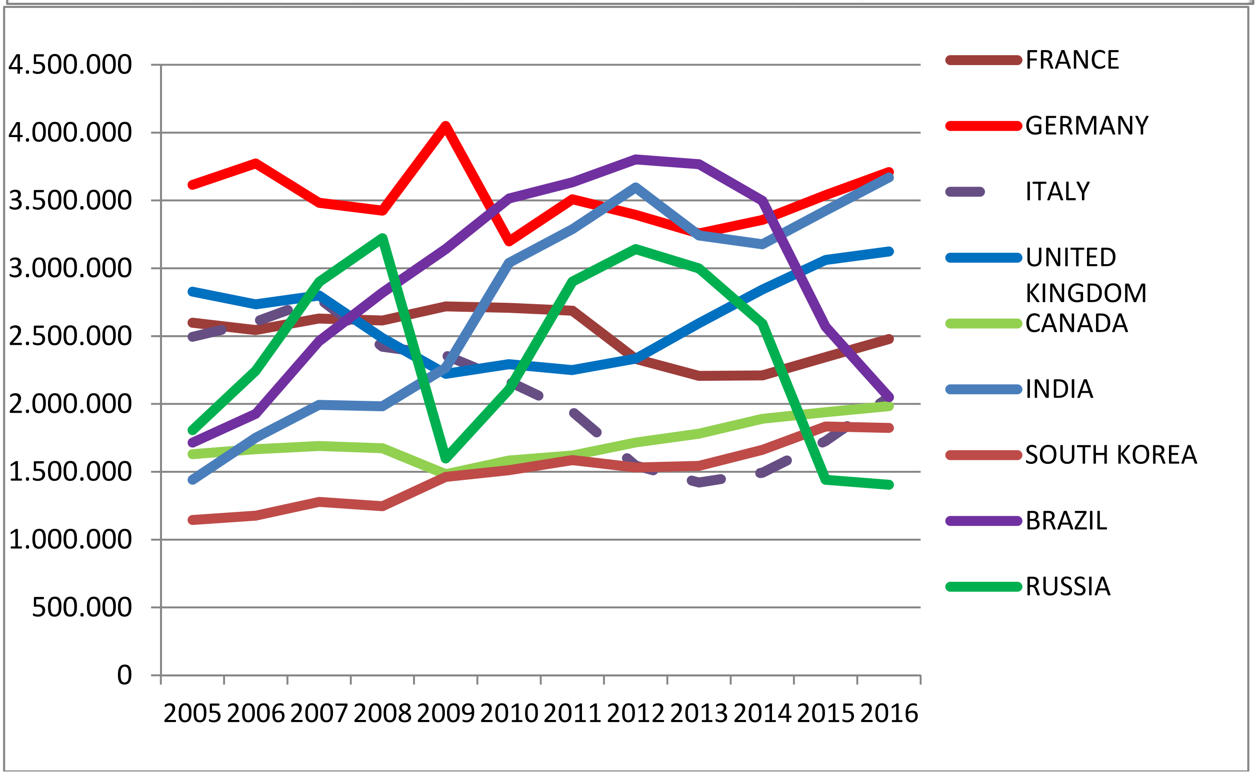
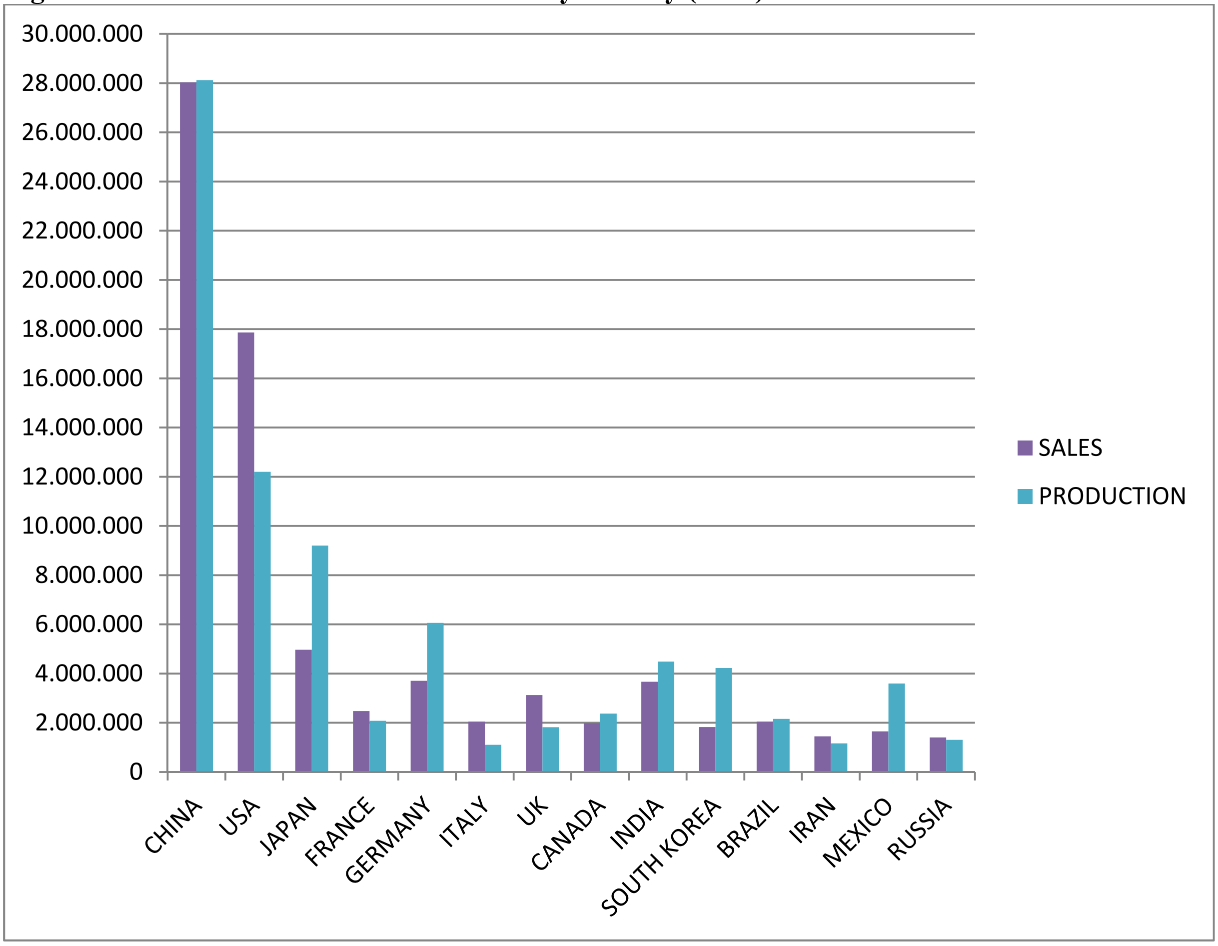


Figure 3.3 Production and sales of vehicles by country (2016)

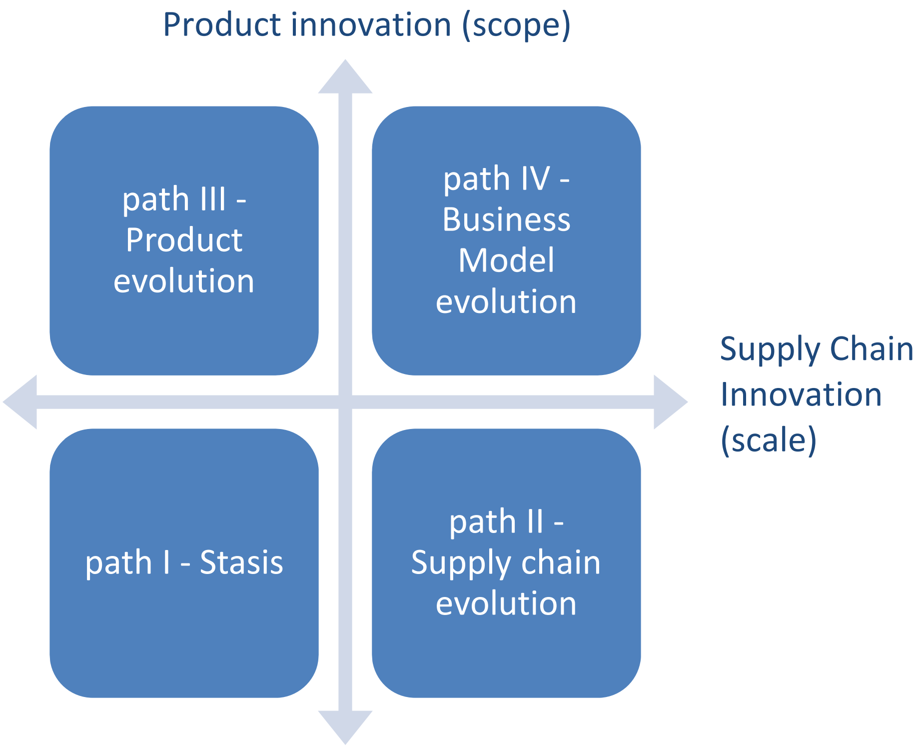


Source: OICA 2017

Global automotive manufacturing is a very concentrated industry with large OEMs and high entry barriers. On the other hand, manufacturing of parts and accessories is very fragmented and competitive. According to Zion Market Research (2017), the global car accessories market was valued at USD 360.80 billion in 2016 and is expected to reach approximately USD 519.01 billion by 2022, growing at a CAGR of around 6.4% between 2017 and 2022.

AM could be a huge opportunity for the whole industry from two perspectives: first, it is a major source of innovation thanks to its flexibility; second, it can transform business models and renovate the actual supply chain. According to Deloitte (2014), AM allows for a reduction in capital to achieve both economies of scope in the design of products and scale in the possible variety of customized items. The trade-off in performance between capital vs scope and capital vs scale is visualized in four paths of value in the adoption of AM in the automotive industry (Figure 3.4).

Figure 3.4 Framework for understanding AM paths and value



Source: Adapted from Mark Cotteleer and Jim Joyce, "3D opportunity: Additive manufacturing paths to performance, innovation, and growth," Deloitte Review 14, January 2014

Most OEMs and suppliers are still on path I, exploring technologies to improve current production, but without substantial changes to products and supply chains. AM allows: i) improved flexibility, speed and quality in the prototyping phase; ii) reduced dependence and costs related to tooling and casting in the design phase and enhanced customization. According to BMW, customized tools helped to save 58% in overall costs and have reduced project times by 92%.[27] For a single component, such as an engine manifold, developing and creating the prototype usually costs about USD 500,000 and takes around four months. Using AM, Ford can develop multiple iterations of a component in just four days at a cost of USD 3,000.[28]

Tier 1 and tier 2 suppliers should investigate exploiting AM capabilities along path II producing components on demand and at locations closer to end users. Competition in the after-sales market will be based on servicification: shorter delivery times and full availability of components but a reduced inventory. For OEMs, the achievement enabled by new business models associated to path IV go through product evolution (path III). In the near term, it will be possible to develop lighter weight components aimed at fuel savings, which would satisfy both environmental regulation and consumers. Another form of cost savings is represented by reductions in the number of components required, simplifying the assembly process and

[27] Troy Jensen, 3D printing: A model of the future, PiperJaffray, March 2013.
[28] Ford Media Centre, "Ford's 3D-printed auto parts save millions, boost quality," in Deloitte (2014).

eventually improving quality. Full customization is already possible in the extreme luxury segment: path IV will be characterized by smaller supply chains and mass customization.

3.5.1 Robotics and Japanese automotives

Japan is home to some of the world's largest automotive OEMs. The Japanese automotive sector currently is characterized by a strong base of OEMs combined with lead suppliers, whose inter-locking business relationships emphasize efficiency, prices and quality (Putra et al., 2016). Production is global; Japanese OEMs are maintaining a presence in cost-competitive and growing locations abroad (Putra et al., 2016). Japanese carmakers are retaining a global share of approximately 30% (Putra et al., 2016).

Japanese carmakers' competitive advantages derive from production efficiency, strategic partnerships and mass production. The sector first emerged when, during the second world war, Japan selected industry champions (in Nissan and Toyota) to meet the country's transport needs. With sector liberalization in the post-ward period, car companies raced for market leadership – most formed strategic alliances with suppliers for critical parts, which led to production modularization and an emphasis on cost efficiency (Schaede, 2010). Automotive OEMs and lead suppliers maintain close relationships that allow the sharing of information on technologies and product design, and critical responsibilities (Kobayashi, 2006; Schaede, 2010). Certain Japanese approaches, such as *kaizen* (the culture of continuous improvement), *keiretsu* (enterprises with inter-locking business interests), and just-in-time (JIT) production (demand-driven supply chains), make the Japanese car making experience distinctive (Putra et al., 2016)[29].

As a result, Japanese car manufacturers are able to enjoy greater quality, cost and product reliability advantages relative to other firms. However, this has some drawbacks: such factors indicate that these carmakers are limited in terms of the innovations they can introduce on the shop floor because any miscalculation could erode the already small profit margins (Putra et al., 2016).

3.5.1.1 Japanese automotive: OEMs and lead suppliers

The degree to which auto manufacturers rely on outsourcing is difficult to pinpoint since it can differ across product categories, product complexity, firm size and the prevailing subcontracting system used within a sub-industry. For instance, Toyota outsources a wide range of its component needs to Denso, from electronic fuel injection systems to air conditioning (Ahmadjian & Lincoln, 2001; Schaede, 2010). Generally, Japanese car manufacturers tend to keep only the production of main parts in-house while they outsource other modular pieces to a small set of closely affiliated firms (Schaede, 2010).

Toyota. Toyota obtains many of its automobile parts from local suppliers, mostly through long-term contract agreements which ensure steady supply and efficient delivery of components. The company is more likely to work with suppliers whose facilities are located

[29] These sensibilities were incorporated into a production system called the Toyota Production System, which was adopted by most Japanese carmakers.

within a 56-mile radius of its plants. Toyota currently maintains a large number of suppliers, varying according to the region of production. Some examples include Fuel Total Systems Corp., TAIHO Manufacturing, OTICS USA, Tesla Motors, Samsung Electronics, Bridgestone Americas Cypress Semiconductor, Magnuson Products, IPT Performance Transmission, Nippon Denso Co., Aisin Seiki Co., etc. (North America) and Aisin.

Honda. Honda also maintains business relationships through long-term contracting across its assembly plants in Europe, North and South America, and Asia. For instance, in North America, from which almost half of 2015 total sales come, some of the main suppliers include American Mitsuba, AGC Automotive, Takata, Nippon Seiki, Nasco, ThyssenKrupp and Automatic Spring Products.

Table 3.22 R&D Facilities of select Japanese automotive companies in Europe.

Manufacturer	Company	Headquarters / Division Office	Current functions
United Kingdom			
Honda	Honda R&D Europe (U.K) Ltd.	Swindon, UK	technical support for procurement of parts for local production, evaluation of parts, evaluation of vehicles, parts design, vehicle design, prototype production
	Honda Racing Development Ltd.	Bracknell, UK	development of F1 racing cars
	Honda GP Ltd.	Brackley, UK	development of F1 racing cars
Nissan	Nissan Design Europe Ltd.	London, UK	styling and general design, parts design, vehicle design, prototype production
Toyota	Toyota Motor Sports Germany GmbH	Cologne, Germany	development of F1 racing cars
Subaru	Subaru Test & Development Centre (STCE)	Ingelheim am Rhein, Germany	evaluation of parts, evaluation of vehicles

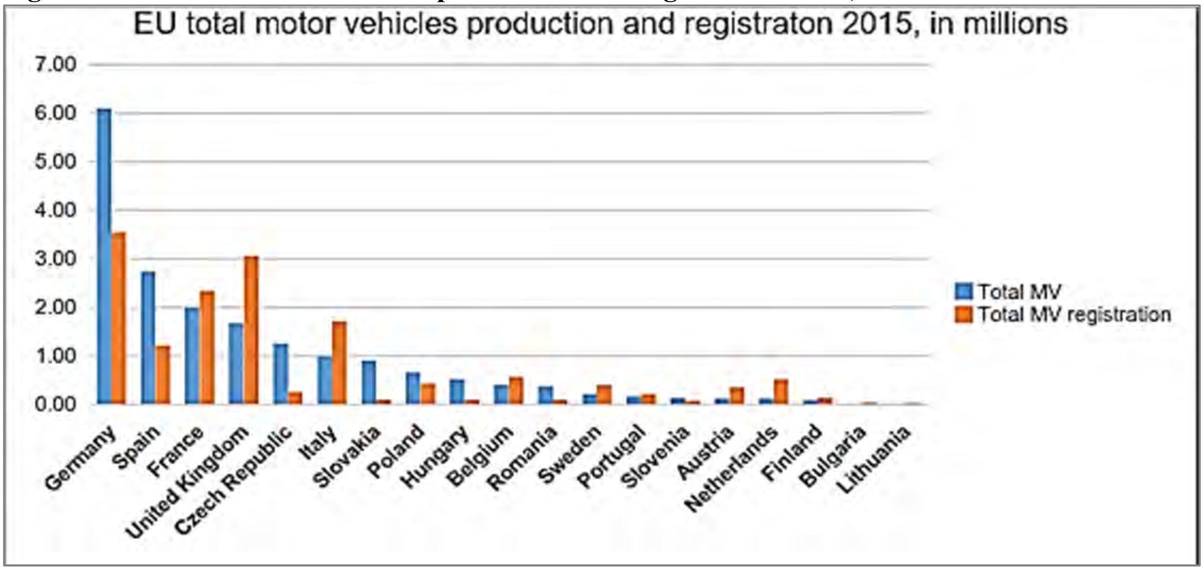
Manufacturer	Company	Headquarters / Division Office	Current functions
Germany			
Honda	Honda R&D Europe (Deutschland) GmbH	Offenbach, Germany	evaluation of vehicles , styling and general design, vehicle design, prototype production, marketing research
Isuzu	Isuzu Motor Germany GmbH	Gustavsburg, Germany	technical support for procurement of parts for local production, evaluation of parts, parts design
Mazda	Mazda Motor Europe GmbH	Leverkusen, Germany	evaluation of vehicles ,styling and general design, vehicle design, prototype production, marketing research
Mitsubishi	Mitsubishi Motors R&D Europe GmbH	Trebur, Germany	technical support for procurement of parts for local production, evaluation of parts, evaluation of vehicles, styling and general design, parts design, vehicle design
France			
Toyota	Toyota Europe Design Development S.A.R.L.	Nice, France	styling and general design, parts design, vehicle design, prototype production, marketing research
United Kingdom / Belgium			
Toyota	Toyota Motor Europe N.V./S.A..	Zaventem, Belgium Bernaston, UK	technical support for procurement of parts for local production, evaluation of parts, evaluation of vehicles, parts design
United Kingdom / Spain/ Belgium/ Germany			
Nissan	Nissan Technical Centre Europe Ltd.	Cranfield, UK Barcelona/Madrid, Spain Brussels, Belgium, Bruhl, Germany	technical support for procurement of parts for local production, evaluation of parts, evaluation of vehicles, parts design, vehicle design, prototype production

Source: Japan Automobile Manufacturers' Association (JAMA, 2017)

3.5.2 Robotics and German automotive

Germany boasts one of the most prominent and valuable automotive manufacturing sectors in the world. Across Europe, 2015 data indicate that Germany is both the largest total vehicle producer and the biggest market by total vehicles registered (see Figure 3.5) (European Automobile Manufacturers Association, 2016). At the national level, the sector is the largest industry by sales (404 billion EUR in 2016) and accounts for a substantial share (around 35%) of the entire German R&D expenditure (21.7 billion EUR in 2016) (Germany Trade & Invest, 2017).

Figure 3.5 EU total motor vehicles production and registration 2015, in millions



Source: European Automobile Manufacturers' Association (ACEA, 2016)

Germany hosts several automotive OEMs and key Tier 1 automotive components suppliers,[30] such as the BMW Group (BMW) Daimler AG (Mercedes-Benz), The Ford Motor Company (Ford), Adam Opel GmbH (Opel), Volkswagen AG (Audi, MAN Group, Porsche, Volkswagen), Robert Bosch GmbH (Bosch), and Continental AG (Continental) (see Table 3.23).

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[30] Tier 1 companies are often regarded as the largest or the most technically-capable companies in the OEM’s supply chain. They often develop close working and business relationships with OEMs (via Investopedia.com and chron.com).

Table 3.23 List of automotive OEMs (and their marketed brands) and select automotive components suppliers located in Germany

OEM Parent company	Brands*	Automotive components suppliers°	
Adam Opel GmbH	Opel	Bosch	Draexlmaier
BMW Group	BMW	Continental	Eberspaecher Holding
Daimler AG	Mercedes-Benz	ZF Friedrichshafen	Getrag
The Ford Motor Company	Ford	Thyssen Krupp	Leoni
Volkswagen AG	Audi	BASF SE	KSPG
	MAN Group	Mahle	Freudenberg
	Porsche	Schaeffler	Webasto SE
	Volkswagen	Bentheler Automobiltechnik	Infineon
		Hella KGaA	Leopold Kostal
		Broze Fahrzeugtechnik	Trelleborg Vibracoustic
			Kautex Textron

* Listed brands are those that have significant operations in Germany
° Automotive components suppliers with German headquarters

Source: Author's classification, adopted from GTAI (2016).

Considering the sector's breadth and scope of activities, it is unsurprising that German carmakers were one of the earliest adopters of advanced technologies and investigators of the Industry 4.0 environment.

The next section examines the advanced technologies and robotics that the major German OEMs (and related brands when applicable) have adopted in their production processes. Similar case studies are presented for the two largest automotive components suppliers in Germany: Robert Bosch GmbH and Continental AG. A brief but comparable discussion is constructed for the automotive supplier SME SEW-Eurodrive to demonstrate that the current technological transformation across the German automotive industry is sector-wide.

3.5.2.1 German automotive: OEMs

BMW Group. Within the automotive space, the BMW Group (BMW) has been one of the pioneers in adopting the most recent technologies in its manufacturing process. Currently, several of the manufacturer's plants in Germany and in the US have been retrofitted with various autonomous robots that enable greater human-robot collaboration (hereafter referred to as collaborative robots or co-bots when applicable) than allowed by traditional machines. BMW's first lightweight robot came online in its Spartanburg, SC plant (BMW Group, 2017a) and allowed the carmaker, together with MIT, to identify that a collaborative human-robot environments results in an 85% drop in workers' idle time and that this combination is more effective than teams of either humans or robots alone (Knight, 2014).

Since then, BMW has capitalized on its knowledge by commissioning more of these robots in its other plants. Today, BMW uses co-bots to undertake tasks such as the lifting of bevel gears during axle transmission assembly (BMW Group Dingolfing plant) and the application of viscous adhesive to front window installations (BMW Group Leipzig plant) (BMW Group, 2017a). Similar collaborative and autonomous robots have been introduced in the company's transport and logistics management: Smart Transport Robots (STR) and laser-guided autonomous tugger trains are employed in the Wackersdorf and Dingolfing plants respectively (BMW Group, 2016c).

The BMW Group also uses other proximate technologies that benefit both humans and robots alike: 3-D printing technology in rapid prototyping, manufacturing validation (MIT Technology Review, 2014), and additive manufacturing (BMW Group, 2016b), laser-based guidance systems (BMW Group Regensburg plant), augmented reality applications and intelligent devices, and robotic exoskeletons for strenuous tasks (BMW Group, 2017a).

Daimler AG. Daimler AG was another early adopter of advanced manufacturing technologies exploring the many possibilities of Industry 4.0. Even before the sector-wide shift, the then Daimler Chrysler was experimenting with agent-based HMS in its Mercedes Benz V6 and V8 engines assembly plant (NVM) in Stuttgart (Bussmann & Sieverding, 2001). Currently, within the Mercedes-Benz brand, Daimler AG has defined and achieved two stages: 1) global component standards, a standardized systems architecture and standardized automation, regulation, and control technologies; 2) globally standardized technology modules for its robotics and production processes. Furthermore, Mercedes-Benz is able to simulate the production process from press plant to final assembly, allowing the car manufacturer to examine 4,000 individual processes prior to actual production (Daimler AG, 2015b).

Various other related technological shifts have been exploited in selected Mercedes-Benz variants: for instance, Mercedes-Benz S Class production recently shifted from its large traditional robotic machines to the smaller and lighter co-bots in the Sindelfingen plant in what the carmaker refers to as "robot farming"; the human workers are expected to provide the required adaptability and the flexibility to achieve mass customization (Gibbs, 2016). For its latest E Class (213 series), the carmaker is implementing a networked and digital-based production approach: 87 body-in-white production systems are equipped with 252 programmable logic controllers, 2,400 robots, and 42 technologies and are linked to approximately 50,000 intelligent network participants (IP addresses), thereby allowing continuous monitoring without human intervention (Daimler AG, 2015a). Unmanned production tracking is enabled by combinations of antennae and Wi-Fi networks. Again, workers become valuable because of the flexibility that they provide in the shop floor (Daimler AG, 2015a).

Beyond its premium vehicle segment, Daimler AG maintains key facilities in its Sindelfingen location that enable it to advance its production processes. An example is the TecFactory, which is a test factory where the company tests new production concepts and ideas, particularly in man-robot cooperation and innovative logistical solutions (i.e. driverless transport systems or DTS) (Daimler AG, 2015b). Another facility is the Virtual Reality Centre which is used for prototype design and virtual prototype simulation, such as the case of the Mercedes-Benz Class E (213 series) (Daimler AG, 2015a).

Daimler is actively involved also in inter-firm collaborative research to advance the current technologies. The carmaker, together with the University of Stuttgart, Fraunhofer IPA, and Bosch, founded the project Active Research Environment for the Next Generation of Automobiles (ARENA2036). ARENA2036 is a public-private platform that investigates agile and flexible production systems and human-robot cooperation (International Federation of Robotics, 2016).

The Ford Motor Company. As part of its efforts to participate in Industry 4.0, the American car manufacturer Ford Motor Company (Ford), has installed co-bots in its Cologne factory. In Ford's approach, the co-bots are relied on to assist the workers in fitting shock absorbers into the wheel arches of its Ford Fiestas: the machines are used to handle the lifting and positioning tasks, while the human workers supervise the installation (Zaleski, 2016). Regarding worker safety, Ford relies on intelligent machines that stop immediately they detect a human presence (even just a finger) in their path (Ford Motor Company, 2016).

Adam Opel GmbH. Adam Opel GmbH (Opel) is still in the early phases of advanced technologies adoption and Industry 4.0 investigations. Rüsselsheim am Main-based Opel's ITEZ – Advanced Manufacturing Technologies (AMT) team, together with its supply chain and manufacturing IT personnel, is actively researching intelligent systems and self-organizing production (Scherer, 2017). Another ITEZ division, called the Structural Development Laboratory (SDL), applies laser-based and simulation technologies to prototyping and testing of brake systems (Scherer, 2016). These internal efforts are supplemented by work done by graduate interns, such as investigations into intelligent self-organizing production (Opel Post, 2016). However, Opel is beginning to adopt smart technologies and intelligent robotics on its shop floor. For instance, it relies on Fanuc R-2000iB, a heavy-duty robot, to work with its human counterparts in door installations for the company's Insignia models in its Rüsselsheim plant (Wollny, 2016). Smart technologies, such as augmented reality devices and wearables, are used for supply chain management in Opel's ADAM vehicles (Opel Eisenach plant) and components assembly (Opel Kaiserlautern plant) (Scherer, 2017).

Volkswagen AG. Production processes in Volkswagen AG (Volkswagen) facilities have been highlighted in the literature because of their innovativeness, such as the employment of RFID technologies during post-production logistics management (Huang, et al., 2009). In the Industry 4.0 landscape, Volkswagen is involved in several initiatives that drive and investigate company-wide implementation of advanced and smart technologies: 1) Data:Lab in Munich, which handles ideas related to big data, advanced analytics, machine learning, and AI; 2) Berlin-based Digital:Lab, which handles ideas related to end-customer engagement (e.g. mobility services); and 3) Smart.Production:Lab in Wolfsburg, which develops both software and hardware pilots and prototypes that are implementable in Volkswagen's smart factories (Volkswagen AG, 2015). The group-wide level of IT standardization for production management was 88% in 2016 (Volkswagen AG, 2016).

In particular, through its Smart.Production:Lab, the carmaker, together with the German Research Centre for AI (DFKI), is carrying out research for the development of greater cooperative human-robot capabilities within the same production space (Simpson, 2016).

Propriety systems will be able to process human waves, gestures and motion, which will allow for greater responsiveness and interaction capabilities in robots (Volkswagen Group Italia S.P.A., 2016).

Simultaneous with the general measures being undertaken at the parent-company level, Volkswagen brands have also adopted market-available solutions. For instance, Audi's Neckarsulm facility was one of the early adopters of co-bots for handling coolant expansion tanks (Euromonitor International, 2016). Another instance is Audi's Ingolstadt facility which combines a high level of automation with a multitude of other advanced technologies, such as optics-driven, low-power laser systems and regenerative braking in lift and conveyor systems. In its Audi A3 body shop, Audi employs robots that roughly equal the number of its employees (800); these machines do most of the more strenuous tasks (Juskalian, 2014).

There are several intelligent systems employed in the Audi Ingolstadt facility: body-assembly is jointly produced by an autonomous group framer and several robotic arms that spot weld the components in place (Juskalian, 2014). Juskalian (2014) refers to the Ingolstadt *automatisierter* Anbau (INTA) – a fully automated door-assembly process that uses an array of sensors, robotic arms and lifts in which the unique combination of technologies allows for efficient handling of A3 body variants and installation of corresponding doors. Audi, together with research institutions, is also using the Ingolstadt facility as a site to investigate the viability of nascent intelligent technologies, such as smart mobile assistants, in industrial applications (Angerer, et al., 2012).

Table 3.24 Advanced technologies of German OEMs in Germany

Parent Firm	Facility name	Plant city	Plant state	Adopted Technology	Targeted production process
BMW Group				3-D printing technology	rapid prototyping; manufacturing validation; additive manufacturing
				augmented reality technology	early-phase concept validations, initial sampling inspections
				intelligent devices	supply chain management
				robotic exoskeletons	supply chain management
	BMW Group Dingolfing plant	Dingolfing	Bavaria	collaborative robots	assembly - axle transmission
				autonomous transport systems	transport and logistics management
	BMW Group Leipzig plant	Leipzig	Saxony	collaborative robots	installation – windows
	BMW Group Regensburg plant	Regensburg	Bavaria	laser-based guidance systems	transport and logistics management
	BMW Group Wackersdorf plant	Wackersdorf	Bavaria	smart transport robots (STR)	transport and logistics management
Daimler AG				standardized systems architecture and automation	
				standardized technology modules for robotics and production	
				simulation technology	
	TecFactory	Sindelfingen	Baden-Württemberg		Investigations in man-robot cooperations and logistic solutions
	Virtual Reality Centre	Sindelfingen	Baden-Württemberg		prototype design and virtual simulation
	Mercedes Benz			autonomous production systems	
				sensor technology	

Parent Firm	Facility name	Plant city	Plant state	Adopted Technology	Targeted production process
Daimler AG	Mercedes Benz Sindelfingen plant	Sindelfingen	Baden-Württemberg	collaborative robots	production - Mercedes Benz S Class
	Mercedes Benz Sindelfingen plant	Sindelfingen	Baden-Württemberg	collaborative robots	production - Mercedes Benz E Class (213 series)
The Ford Motor Company	Ford Cologne plant	Cologne		collaborative robots	installation - shock absorbers
Adam Opel GmbH	ITEZ - AMT	Rüsselsheim am Main	Hesse		Investigations on intelligent systems and self-organizing production
	ITEZ - SDL	Rüsselsheim am Main	Hesse	laser-based sensor technology	prototype design and virtual simulation
				simulation technology	
	Opel Rüsselsheim plant	Rüsselsheim am Main	Hesse	collaborative robots	installation - doors
	Opel Eisenach plant	Eisenach	Thuringia	intelligent devices	supply chain management
	Opel Kaiserslautern plant	Kaiserslautern	Rhineland-Palatinate	intelligent devices	assembly - automotive components
Volkswagen AG				standardized systems architecture and automation	
				sensor technology	
	Data:Lab	Munich	Bavaria		Investigations on big data, advanced analytics, ML, and AI
	Digital:Lab	Berlin	Berlin		Investigations on CRM
	Smart.Production:Lab	Wolfsburg	Lower Saxony		Investigations on smart production
	Audi Ingolstadt plant	Ingolstadt	Bavaria	laser-based sensor technology	transport and logistics management
	Audi Neckarsulm	Neckarsulm	Baden-Württemberg	collaborative robots	supply chain management
				collaborative robots	supply chain management
					assembly - body
					installation - doors

Source: author's analysis

3.5.2.2 German automotive: automotive components lead suppliers

Continental AG. Continental AG (Continental) has implemented several Industry 4.0 technologies in its Regensburg facility: networking co-workers, co-bots, and driverless transportation systems (ROI Management Consultants, 2015).

In its other lines of businesses, particularly tyre manufacture, Continental has established its High Performance Technology Centre (HPTC) in Continental Corporation's Korbach location. HPTC machine and equipment are equipped with sensors and software, allowing for the emergence of a complete network. The system allows for continuous display and complete documentation of all the processes and materials involved (Continental Corporation, 2016b) using data to run simulations and investigations of tyre variants, thereby reducing development time (Continental Corporation, 2016a).

Robert Bosch GmbH. Bosch's automotive plant near Immenstadt im Allgäu, Germany, is a testbed for intelligent manufacturing processes that the company might implement across its facilities. The plant is equipped with various advanced technologies: sensor (RFID) technologies and digital twins are made available in all machinery and tools, allowing plant managers to obtain real-time information om plant efficiency and health (Juskalian, 2016). Moreover, Juskalian (2016) explains that the facility is connected to a main data centre in Stuttgart, where granular data from 11 Bosch facilities are consolidated and analysed.

Bosch is also one of the founding members of ARENA2036 (see *Daimler AG*).

SEW-Eurodrive. SEW-Eurodrive's factory in Baden-Württemberg features several robotic technologies that aid its human workers: 1) a robotic workbench that assembles near-complete drive systems; and 2) robotic arms that assist workers in load handling (Hollinger, 2016).

Table 3.25 Advanced technologies of German automotive suppliers in Germany

Parent Firm	Facility name	Plant city	Plant state	Adopted Technology	Targeted production process
Continental AG	HPTC	Korbach	Hesse	sensor technology	machine health and prognostics management processes and materials behaviour documentation prototype simulation
		Regensburg	Bavaria	collaborative robots autonomous transport systems	
Robert Bosch GmbH		Stuttgart	Baden-Württemberg	big data analytics	machine health and prognostics management
		Immenstadt im Allgäu	Bavaria	sensor technology	machine health and prognostics management
SEW \Eurodrive			Baden-Württemberg	collaborative robots	

Source: author's analysis

3.5.2.3 German automotive: German cars

Current-generation driver assistance systems. German OEMs have at least kept pace with other leading carmakers across the world in use of the latest technologies in driver assistance systems such as autonomous self-parking, lane-keeping and cruise-control, and traffic jam assistants.

For instance, the BMW i3 model is the first car to offer a fully automatic parking option (BMW Blog, 2014). Other BMW variants, Mercedes-Benz offer hands-off and feet-on technologies while Audi and Volkswagen offer experimental vehicle-to-infrastructure (V21) communication alongside other features (IEEE Spectrum, 2014d).

The Volkswagen Touareg has one of the more advanced lane keeping systems on the market and can track lanes at night-time (IEEE Spectrum, 2014c). Volkswagen has advanced the technology in its other models by allowing the system to continuously counter-steer to maintain the vehicle in its lane (Passat CC) (Volkswagen, 2017). BMW currently offers lane departure warning systems while Mercedes-Benz have lane keeping technologies. All German OEMs have cruise-control technologies, although BMW variants are notable in providing low-speed steering capabilities (IEEE Spectrum, 2014a).

Among the most recent German vehicles available in the market, the Mercedes Benz E Class (213 series) is among the most advanced: the car is equipped with ultrasonic sensors and a 360° camera for traffic analysis and accident prevention (Daimler AG, 2015a). Daimler AG (2015a) states also that the E Class (213 series) has the firm's latest car-to-X communication technology, remote parking pilot via smartphone applications, and a digital vehicle key through near field communication (NFC) technology.

Next-generation automotive systems. Several initiatives among German OEMs and German Tier 1 automotive suppliers are being carried out to investigate next-generation vehicles systems. While some firms conduct their investigations internally, most are carried out in collaborative inter-firm (and sometimes including a research institution) environments.

Bosch currently is working on an advanced braking system which allows the car to take over control from the driver in situations where it identifies potential accidents (IEEE Spectrum, 2014b). IEEE Spectrum (2014b) explains how the car processes information through sensory data acquired by means of a chip installed in the windscreen; it returns control to the driver when it concludes that the danger has passed.

Continental is working with the University of Oxford and the Technical Universities in Darmstadt and Munich on investigating the application of neural networks in the cameras of its advanced driver assistance systems (Continental Corporation, 2017). In 2015, Continental, Deutsche Telekom, Fraunhofer ESK and Nokia Networks h demonstrated the viability of real-time communication between vehicles via the LTE network; the research has the potential for latency reduction of car-to-car communication and viability of existing networks for connected motorways (Continental Corporation, 2015).

Among German OEMs, BMW, together with the Israeli firm vehicle safety systems provider, Mobileye, and chip maker Intel, will begin testing vehicles that rely on a reinforcement learning approach in second half of 2017 (Knight, 2017; Etherington, 2017; BMW Group, 2017b). The carmaker is concentrating its development resources in

Unterschleissheim, near Munich, and intends to release self-driving, electric, and fully connected vehicles by 2021 (BMW Group, 2016a).

Another BMW endeavour is the generation of real-time data through camera-based Advanced Driver Assist System (ADAS): the car manufacturer is working with Mobileye to equip its 2018 vehicles with Mobileye's Road Experience Management (REM™) data generation technology. The collaboration will allow BMW vehicles to access and contribute to Mobileye's Global RoadBook (GLRB™), a crowd-sourced collection of HD maps with highly accurate localization capabilities. The agreement allows both parties to further promote automated driving (BMW Group, 2017c).

Daimler AG and the UK-based Delphi are currently experimenting with the installation in its vehicles of up to four Light Detection and Ranging sensors (LiDARs), devices that map the environment in 3-D with lasers (Simonite, 2016). Simonite (2016) notes that Daimler has invested in the technology company, Quanergy, for the development of next-generation LiDARs.

Recently, Volkswagen AG presented a concept for an autonomous self-driving car called Sedric. It is a level-5 autonomous driving concept car which was designed and constructed by the Potsdam-based Future Centre Europe and the Wolfsburg-based Volkswagen Group Research (Volkswagen AG, 2017). The car is envisaged as a battery-powered electric vehicle with no conventional controls and operated through remote control (Noakes, 2017). Volkswagen AG also is actively investing in ride-sharing technologies, such as Israeli-based ride-hailing service Gett (Kokalitcheva, 2016).

Like its parent firm, Audi has been active in researching future technologies. Recently, the car brand created a new subsidiary, Autonomous Intelligent Driving, which will work for the entire Volkswagen Group to research self-driving technology (Korosec, 2017). Across its vehicles, Audi is working with the technology firm, NVIDIA, to develop the Audi Q7. NVIDIA's DRIVE PX 2 in-car computer is the foundation for the local neural net in the Audi Q7; primarily, it studies driver behaviour and uses the data to infer behaviour (Etherington, 2017). A consortium of Audi, Ericsson, Qualcomm Technologies, SWARCO and the University of Kaiserslautern, is to carry out demonstration trials for vehicle-to-everything communications through 4G/5G LTE-based vehicle-to-network (V2N) technology (IEEE Connected Vehicles, 2017).

Environment for next-generation automotive systems. Regarding the overall environment for the development of networked driving, the German Federal Ministry of Transport and Digital Infrastructure on the following areas of action: Infrastructure law, innovation, networking, and IT security and data protection (VDA, 2016).

Existing German regulation, particularly the Road Transport Law and the Road Traffic Act, allow the use of automated systems, but make no exact provisions in the case of accidents that involve self-driving cars (VDA, 2016). However, in October 2015, Germany adopted the Vienna Convention on road transport, which permits automated driving in traffic, provided that these technologies can be overridden by the driver any time (UNECE, 2016).

Various initiatives are investigating the proper standards for the vehicle-to-X communications network infrastructure (see *Next generation automotive systems*). The

German automotive association, the German Association of the Automotive Industry (VDA) has worked with the federal and state government data protection authorities to develop a standard on data protection aspects of use of networked and non-networked vehicles (VDA, 2016)

3.5.3 Piemonte and Torino

Piemonte represents the most developed region within the Italian automotive sector. The past and recent history was characterized by the important presence of the FCA group (FIAT SPA until 2014). FIAT allowed massive development of companies linked to the local automotive eco-system, which, over the decades, have been specializing throughout the automotive supply chain (product development, components, design, output, after sales).

According to the latest data provided by the Italian automotive components Observatory 2016, Piemonte significantly increased its automotive productivity and revenue in 2015. Within the region there are 712 companies, which represent more than 36% of total Italian suppliers. There are more than 77,000 employees in the supply chain, 55,500 in the automotive industry.

In 2016, FCA production in Italy was 721,126 cars (+8.2% on 2015 and +84% on 2013). Most of the production is concentrated in the South (Melfi, Pomigliano and Cassino), but Mirafiori-Torino and Grugliasco are still relevant for bodywork production of Alfa Romeo and Maserati. Italian factories employ almost 34.000 workers.

Table 3.26 Data on the Piemonte automotive industry.

Automotive Industry	Italy	Piemonte
Firms	1.956	712
Revenue	38.8 billions	15.2 billions
Employers	136.000	55.400
Export	75%	81%
Export revenue	+ 4,2%	+ 3,3%
% of export revenue	40%	45%
Dependence on FCA	79%	87%
R&D	72%	74%

Source: Moretti A., Zirpoli F., (2016), "Osservatorio sulla componentistica automotive 2016", Ricerche per l'innovazione nell'industria automotive, Edizioni Cà Foscari.

The FCA group is not only the main group in the automotive sector in Piemonte but is also a starting point for satellite activities in the region. Over 85% of the companies interviewed for the Observatory report said that part of their revenue came directly or indirectly from FCA, while the national figure stands at 79.9%.

Considering the entire automotive industry, Piemonte is able to generate a total revenue of EUR 19.9 billion, a 6.5% increase with respect to 2014. That accounts for 39% of Italian sales in automotive.

Table 3.27 Firms, Employees and Revenue of the automotive Supply Chain – Piemonte Region

2015	Firms	Revenue Automotive Supply Chain (Bn of Euro)	Revenue Automotive Industry (Bn of Euro)	Employees Automotive Supply Chain	Employees Automotive Industry
Sub-providers	351	2.499	1.442	13.369	7.366
Specialist	242	10.568	7.630	39.716	24.942
Engineering & Design	86	749	652	4.905	4.287
Systems Engineers	33	6.090	5.487	19.455	18.832
Tot.	712	19.906	15.211	77.445	55.428

Source: Moretti A., Zirpoli F., (2016), "Osservatorio sulla componentistica automotive 2016", Ricerche per l'innovazione nell'industria automotive, Edizioni Cà Foscari.

What appears to be an interesting updating about the increased production in Italy and Piemonte, is the change in the production mix. In fact, the production of higher unit volume segments, such as Monovolume and Suv, has increased considerably, while lower band production (A, B, C) was reduced.

Table 3.27 shows the most developed and productive sectors in the Piemonte automotive supply chain, where the specialist segment plays a crucial role.

Piemonte is the main actor in Italy for development of research and innovation. The Piemonte region invests EUR 2.4 billion of in-house resources in innovation, equal to 17% of total spending on R&D by Italian companies.

The entrepreneurial sector invests 78% of its regional expenditure on innovation (the average for Italy is 54%). Innovation is realized mainly in the specialized ICT segment and advanced specialist services. Those firms that are more innovative are characterized by smaller employment (less than 50 employees), less than five years of activity, and average investment of 4% of their turnover in R&D activities.

This strong inclination for product innovations in the field of advanced ICT and advanced services is generating positive effects in many segments of the regional automotive supply chain, as well as influencing the component sector. Data show that in 2015, 74% of component companies were involved in innovation activities (8% more than in 2014).

Two crucial segments in the field of R&D investment are subcontractors, and engineering and development. While the first appears to be the less innovative within the supply chain due to the production of essentially standard components, engineering and development activities are highly innovative.

In Piemonte, the engineering and development segment accounts for 16% of the entire chain (against an Italian average of 12%). This is evidence of significant regional performance in the field of innovation and development of state-of-the-art engineering solutions. Combined with a great propensity to innovate in the field of specialized services and ICT, this allows Piemonte region to act as the national innovation leader in the automotive sector. As already mentioned, the Piemonte automotive sector is characterized by the presence of the FCA Group which, together with CNH Industrial, represents the two main manufacturers in the automotive sector in the region.

Around these big groups, one can find both important firms along the supply chain, as shown by the industry overview, and important companies that represent the region's excellence in research, components and, most importantly, design.

Table 3.28 Main competitors – Piemonte Region

Group	Firm	Employees	Location	Activities
FCA				
	Fiat	5.001-10.000	Torino, TO	Manufacturing
	Maserati	501-1000	Grugliasco, TO	Luxury Production
	Magneti Marelli	2.001-5.000	Venaria, TO	Manufacturing
CNH Industrial		Over 10.000		
	Iveco	1.001-1.500	Torino, TO	Manufacturing
	New Holland	251-500	San Mauro Torinese, TO	Manufacturing
General Motors				
	Global Propulsion System	501-1.000	Torino, TO	Engineering Research Centre
Valeo		1.001-1.500	Pianezza, TO	Components
Pininfarina		501-1.000	Cambiano, TO	Design
ItalDesign – Giugiaro SPA		501-1.000	Moncalieri, TO	Design
Jac Italy Design Centre		51-200	Pianezza, TO	Design

Source: Moretti A., Zirpoli F., (2016), "Osservatorio sulla componentistica automotive 2016", Ricerche per l'innovazione nell'industria automotive, Edizioni Cà Foscari.

As already mentioned, FCA has a significant impact on local suppliers. The reopening of many of the group's manufacturing facilities and the recovery of the automotive industry globally and locally, have contributed to the multinational's re-emergence as a customer for many component suppliers in the region.

Despite progressive diversification in local suppliers' customers in the last few years, since 2014 the trend has changed. Analysis of the distribution of Piemonte's turnover generated by supplying FCA, shows the impact of the group has grown compared to the recent past. This is true more especially for the regional cluster than for the rest of Italy. More than 86% of companies stated that part of their revenue for 2015 came from direct or indirect relationships with FCA. That value decreases to 79% when we consider the Italian level. The detailed percentages show that almost 34% of Piemonte companies earn more than 75% of their revenue from the Italian-American group, against 29% earned by other Italian companies.

In 2014, the average percentage of (direct or indirect) supply to FCA decreased (32%), but in 2015 the share rose again to 49%. This growth was experienced not only by the domestic market (33% vs 26% in 2014), but also by the average percentage of sales for foreign production (16% vs 6%).

There are some interesting aspects to the degree of openness to the foreign market based on prospect data. Subalpine businesses historically have been characterized by a high degree of openness to foreign markets. This propensity allowed the chain in Piemonte to overcome the recent global economic crisis, which severely affected the car market, and to maintain high levels of competitiveness and entrepreneurial specialization.

After 2014, when component sales abroad had halted, Piemonte exports continued to grow and reached nearly EUR 4.5 billions (about 37% of Italian car exports) in 2015. This represents an increase of 3.1% compared to the previous year.

In 2015, for the first time in ten years, the value of sub-alpine car sales exceeded those of parts and components, increasing by 33% compared to 2014 (EUR 5.8 billions). This was due to the expertise and experience in the Piemontese entrepreneurial system, acquired over the years, particularly in the Turin area where FCA produces some Maserati and Alfa Romeo brands. Today, Piemonte automotive exports account for almost 30% of domestic car sales abroad, a share that has increased progressively in recent years (21% in 2008). This confirms the importance of the Subalpine territory in an international context.

The opening of Piemonte companies to foreign markets is confirmed by the responses to the Observatory survey: in the last edition of the Observatory, 81% of Piemonte suppliers (79% in 2014) declared being exporters, against 75% of suppliers nationwide. The greater propensity to export is supported by the degree of intensity with which companies rely on it: for one quarter of the sample surveyed, export accounts for more than 75% of the turnover.

4 Policy actions

We are keen to avoid rehearsing the lists of general policy recommndations proposed by numerous reports written during the last 18 months on the development of the digital manufacturing. Here, we offer a concise set of actions that could be implemented in the next 18 months, focusing particularly on Torino and Piemonte, but as part of the larger macro region of North Italy.

Torino and Piemonte can rely on extensive and state-of-the-art knowledge on machinery and robotics, which are embedded in a production system that suffered greatly in the last economic crisis, but which has managed to survive thanks to significant investment in innovation. Indeed, a growing share of R&D in GDP is evidence of an innovation-oriented business environment in Piemonte; this share is the highest among the Italian regions, about 2.2% in 2014 (see Table 1.6). Innovative companies have managed to substitute lack of internal demand for export-led growth, which is a reconfirmation of their competitiveness. Significant economic growth in 2017 combined with investment and an increase in internal demand for manufacturing goods (see forecast return to 2 million cars sold in Italy) should be a good predictor also of increased demand for the automotive supply chain, which still plays a very important role in Piemonte. We believe that this trend should enable increased local growth in line with the higher rates experienced over the last 18 months in Lombardia, Emilia Romagna and Triveneto. However, this positive scenario should be seen against the relative lack of digital industry skills. The generation and diffusion of new Cyber-Physical Systems (CPS) characterizing digital manufacturing are requiring the integration of high-level technological and organizational skills, which currently are lacking in these areas.

However, a catch-up in AI (AI) and Computing Technologies is possible, for several reasons:

1. In the past, Torino has proven able to shift its specialization pattern.
2. Piemonte has been home to Olivetti's computer developments and production and established Telecom Italia's operator lab (CSELT, now Tlab). Arduino, an open-source platform that is known worldwide, can be considered as an example of a spillover from a technological ecosystem, which never disappeared.
3. Torino hosts some important AI and computing science organizations – both academic and non-academic - which can act as the first pivots of future further developments.
4. Other regions with a specialization in machineries and robotics, such as Bayern, seem to have had the ability to make rapid transitions and become leaders in CPS.

Torino and Piemonte are players within a larger geographical area that includes, at least, Lombardia, Emilia-Romagna and Triveneto, which, were they more integrated, generate a critical mass of human capital, industry and financial advantages in order to compete globally. With a population comparable to that of the BENELUX countries and similar education, technological and industrial performance, this macro-region could emerge from the most recent and long recession to achieve GDP growth rates not seen for a long time. However, the window of opportunity is narrow and within the next few years the list of global players in the field will close.

The end of the 19th century and the early 20th century, the dawn of the second industrial revolution, saw Torino (Piemonte), Milano (Lombardia) and Genova (Liguria) achieving crucial industrial catch-up, which laid the foundations for the post war Italian 'miracolo industriale'.

The larger quadrilateral roughly connecting Torino, Venezia, Bologna and Genova (with Milano in th centre of the Torino-Venezia link) could become the core of an immediate future wave of industrial and technological developments, building also on geographical proximity to Europe's power house, that is, Germany and the growing Eastern European economies.

The following suggestions focus on policies with a clear emphasis on supporting the generation of the **human capital** required to develop the capabilities that will become integrated with existing skills in machinery and robotics. These policy actions concentrate on the creation of regional shared public goods (club goods) based on industrial commons. Actions to a) elevate technological trajectory, b) de-risking innovative investment, c) accelerating the pace of change and d) building the cognitive capacities will enable SMEs firms to compete in Global Supply Chains. These policies should be aimed at driving activities and all could be delivered in full in the next 18 months with relative low investment efforts.

Masters and PhD Courses in apprenticeship

According to Italy's National Engineering Council (Consiglio Nazionale degli Ingegneri), there are around 18,000 engineers in Piemonte (10,000 in Torino), 40,000 in Lombardia, and about 24,000 in Emilia Romagna. Engineers with degrees in either automation or computing technology represent less than a third of these numbers. A plausible target among this population of engineers for training policies in AI and computer science integrated in robotics and automation would be in the range 800-1000 bearing in mind the age limits for the programmes described below. This engineering workforce has little training in computer technology or AI; however, it has the required absorptive capabilities and skills.

Masters and PhD in apprenticeships are public programmes that create incentives to combine **formal** degrees at either the Politecnico of Torino or the University of Torino, with on-the-job training. Students enrolled on these programmes are hired by firms, which benefit from around a 30% reduction in labour taxes compared to what the firm would have to pay for an employee of a similar seniority. There are currently few apprenticeship schemes available in hard science and social sciences. We call for wider use of these important schemes, focused on AI and its integration with digital automation. Masters level students receive 400 hundred hours of teaching over two years. Doctoral level students are given less teaching time, but develop an applied research project within the relevant company. Estimated training costs are EUR 4,000 per trained individual per two years at master's level, and EUR 12,000 per trained individual per three years at doctoral level; these estimates exclude grants or scholarships because the students enjoy financial advantages from being employed by a company. We obtained these estimates based on the present standard costs paid by Regione Piemonte.[31] Excluding fiscal advantages, a reasonable investment would be around EUR 5 million over three years for 900 master's positions and 100 doctoral positions.

ITS courses to train human capital

Supporting the transition from traditional manufacturing to digital manufacturing requires a supply of trained personnel - and as soon as possible. Production processes require not only graduates but also specialized technicians, who can receive tertiary education training in technical schools in two years. Compared to Germany and France, Italy has lagged behind in developing this type of higher education, which can be seen in the lower share of graduates in the Italian population. More than 15 years after the introduction of the 3+2 Bologna system, most Italian students still tend to participate in the full five-year university programme (Alma Laurea). The first (not very successful) attempts to develop a 'Lauree Brevi' (2-3 year HE degrees) were made between the mid-1980s and mid-1990s. In 2011, the Istituti Tecnici Superiori (ITS – Higher Technical Institutes) were introduced in Italy; Piemonte is already reaping the rewards.

ITS in Piemonte[32] are organized in seven schools and cover various areas, such as innovation, mobility, tourism, culture and fashion, energy and biotechnology, which have a large socio-economic impact. The strengths of this form of education, in which the Region Piemonte has invested EUR 15 million for the period up to 2020, include co-design of profiles and skills, support and advice on job placement, rapid adaption of profiles to business needs, transfer of innovations, focus on work objectives and practice, high-level apprenticeships and internships. So far, ITS in Piemonte are achieving employment rates of over 80% within six months of graduating and the dispersion rate is stable and below 20%. The number of students enrolled is increasing, from 80 students in years 2011/2012 to 400 in years 2017/2018 (only 75 places available to study aerospace and mechatronic). The most recent two years' courses include both classroom hours and internships. We call for more efficient use of this tool together with an expansion in the range of activities to include computer programming and data science. The sum of EUR 4 million over 2 years would cover the cost of training an additional 800 students.

[31] Information on Higher Education and Research regulation in Piemonte is available at the Regione Piemonte website http://www.regione.piemonte.it/apprendistato/duale_ricerca.htm

[32] More details can be found at www.itspiemonte.it/

Continuous learning on the job and an open knowledge repository

The two year ITS higher education programme could be complemented by a system of online training that would allow workers to continue to update their skills. Such an online system, premised on the ITS courses, would benefit from the alumni network and support infrastructure. In any year, ITS students would have to chance to follow the online courses and to spend a small number of days in the classroom. Older workers who had not benefited from the ITS training could be enrolled in the online courses based on access tests and completion of preparatory courses (online and in the classroom), which would award them with the necessary credits for entry to the ITS. This hybrid system would benefit from an esprit de corps engendered by participation in a similar course (an example is ITS Torino 2018 Digital manufacturing, which creates incentives for workers to continue learning and sharing their knowledge). To facilitate knowledge sharing at the local level (creation of a club good), the physical infrastructure of the ITS could become the locus for the creation of an online repository of software, best practice, data, etc, which could be accessed by all accredited ITS students. A fix cost of about 0.5 million a year would be more than sufficient for the development and maintenance of such a system.

Attracting Human Capital: brain circulation and attraction of talent

Italy has suffered from a longstanding brain-drain problem, which has not been balanced by brain-gain from other countries. Young and educated pupils tend to emigrate and not return, whilst, also, Italy, has not held any attraction for young professionals, despite the financial incentives that have been introduced for 2017.

Italian law grants a tax exemption over three years, on 90% of the salaries of both Italian and foreign researchers willing to relocate to Italy. However, the outcome of this policy has not been entirely satisfactory, and only about 4,000 researchers profited from this opportunity in 2016 (note that this number could include individuals who would have come to Italy in any case, so may be an over-estimate of the impact of this policy). Moreover, few foreign professionals emigrate to Italy, although the policy specifically includes foreigners in potential candidates. The reasons for this poor results are related to labour demand and supply. On the demand side, companies in Piemonte and Italy, more generally, are not necessarily open to foreign employees due to cultural and language barriers[33]. On the supply side, foreign professional are put off by the bureaucratic procedures involved in the relocation process. Since it is not possible, in the short term, to reduce the cultural barrier in many firms, a strategy designed to help the rapid assimilation of foreign workers could be introduced consisting of an ad hoc service to help to overcome the bureaucratic and language barriers, and provision of intensive language classes. Active efforts to be made to identify foreigners interested in living and working in Italy (Italy is attractive from a quality of life and value for money perspective). Priority could be offered to engineers and scientists with at least five years' work experience in a digital manufacturing employment. We would suggest that the city of Torino (Milano, Bologna) should set a target of 2,000 new young digital manufacturing field professionals from abroad, and offer them additional benefits to those

[33] Positions are often advertised in Italian only and the job description is in Italian.

offered by the state (during the first and second industrial revolutions, Piemonte passed laws to create incentives for foreign inventors to locate their production activity in Piemonte).

It should be noted that the relocation choice often is not driven solely by the available job opportunities. According to LinkedIn Global Talent Trends 2015, compensation is a top priority, along with other aspects and especially in the case of the creative industries (Florida, 2001). The city environment in which a specific job is located is an important determinant of this choice, as are the richness and diversity of the city, its natural and cultural amenities and the presence of a university (Florida, 2011)

Piemonte and Torino do not lack cultural amenities, as clearly testified by the continuous increase in tourism after the Winter Olympic 2006 that repositioned the city on the international map. Moreover, Torino should take advantage of its comparable to other cities low cost of living. However, the city of Torino needs to implement a city branding strategy to advertise working conditions and benefits, career opportunities, the knowledge environment and the city amenities in the international job market. Milano has been much more active in rebranding itself as an international city and Torino might learn from its so far successful experience.

Coordinating Organization

A well-performing innovation system needs specific organizations able to act as devices enabling the coordination of efforts among system actors such as the Politecnico di Torino, the University di Torino, private and public research institutions and private companies towards the development of an applied technology ecosystem. A successful organization would become a landmark and help to promote the city of Turin in line with the branding strategy suggested above. The current Officine Grandi Riparazioni developments are moving in this direction, but more work is needed and competition among different organization addressing different potential but overlapping demands (spin-off generation versus support for SMEs) is welcome.

The Politecnico hosts several research groups dealing with both smart automation and AI; similarly at the University, many Departments led by the Department of Computer Science are active in computing sciences and AI and recently have built the high-performing-computer Occam, which is becoming a sand box for researchers in the field. The role of Higher Education Institutions should not be considered as confined only to formal education; they should also be imparters of knowledge that will contribute to the development of the economic environment. They can profit from interaction with firms, which would allow them to focus research on specific issues. However, not all the knowledge created in academia is integrated in the system. Combined with the proprietary nature of the knowledge created in the private sphere, competition can generate duplications of research efforts and lose profitable exchanges, hindering joint research activities and, ultimately, damaging the economic performance of the system as a whole. Since global competition in the sector is intense, and the areas positioning in the ranking is not well established, the costs of knowledge diffusion can be high. Since neither market forces alone nor the good will of single individuals rarely create effective coordination (creation of a club good in the production of knowledge), there is need to coordinate public-private interventions. There are several examples of coordination achieved through the creation of ad hoc organizations tasked with integrating the knowledge in the ecosystem. One of the most successful of such cases is the German Fraunhofer-Gesellshaft. The Fraunhofer-Gesellschaft is an organization devoted to applied research. It is organized into activities in 69 research units located in Germany. Its annual budget is EUR 2.1 billion, 1.9 billions of which come from contracts. Clearly, this initiative is on a different scale from a potential knowledge hub in Turin, but it shows that such institutions can rely almost exclusively on private financing and competitive research grants. Another example is the UK's Catapult programme, which is a network of physical research centres designed to conduct applied research that matches business needs to academic knowledge. Each centre receives public funding of EUR 10 million on average, with a similar additional amount coming from competitive grants and business contracts. Although a similar programme might benefit Italy, initially, we suggest the setting up in Torino of one institute similar to a node in the UK Catapult, in the converging areas of AI and automation. Such an organization would interact with and benefit from the Italian Institute of Technology (IIT) located in Genova and the coming Human Technopole (HT) in Rho-Fiera. During the last few years, a large number of new initiatives to support the creation of spinoffs have been launched in Torino. The organization that we are recommending would have a primary objective of bridging between universities, public research centres, large firms and small and medium sized firms to achieve knowledge exchange and knowledge creation. This would involve large and small companies that are attempting to make the transition into digital manufacturing, and knowledge creators such as the Politecnico, the University, IIT, HT etc. Spinoffs might result from, but are not the focus of this activity. The goal is digital rejuvenation (through the transformation of production and organization) to enhance competitiveness.

There are many examples in Europe of similar types of institutions, which have all been successful in developing new products and processes in different high-tech areas. They have managed to find matching funding via business contracts and competitive grants and all require some basic funding that should be higher in the year of establishment and then gradually decrease. For instance, Innovate UK, a government economic development agency, in 2013 invested about GBP 100 million in Catapult centres. This amount of funding has reduced drastically over time. We think that the minimum investment required to establish such an institution would be EUR 10 million per year for the first three years, followed by an exit strategy related to public investment. Private companies and local private foundations should be interested in supporting the creation and development of such an organization.

The location of the suggested institution is of prime importance, since it can become a hub for as many related activities as possible, and should increase personal contacts and exchanges of tacit knowledge. In the context of the other policies suggested above, the institution should support teams scouting for international professionals, branding the city and helping foreigners to relocate to Italy. It should have at its disposal temporary housing for foreign professionals, while it can be the home of the ITS in Digital Manufacturing. It should become a physical emblem of the emergence of the city of Torino as specialised in advanced technology, which would contribute to the city's branding efforts and help to attract relevant talent. Preliminary discussions with the "Agenzia del Demanio", which manages public owned but dismissed areas for the Italian government, suggest that there are several areas in the city where such an organization could be located. Using a public dismissed area would reduce building costs to almost zero and reduce subsequent rents, which would be payable to the public owned investment fund that would finance the restructuring. The cost of refurbishing a large area, only partially used by the new bridging organization, might be around EUR 100 million and EUR 2-3 million per year an adequate return of investment from the public owned investment fund. That means that the property should be rented by other commercial activities to cover a significant share of the 2-3 million rents.

This set of policies does not constitute an optimum policy-mix for the industrial development of the area but rather the minimal set of feasible actions which can be immediately implemented at a reasonable cost. They have the purpose of exploiting the narrow window in order not to pass up, once again after the failure of the Olivetti, the opportunity of competing as a leader in the digital technologies. The long-standing problem of the Italian stagnation and the role of very broad investments in industrial policy is not a matter discussed in this report, but it is surely a key issue to be addressed by Italian policy makers.

APPENDIX I

Here we report two illustrative cases of reshoring in Italy, extracted from the European Reshoring Monitor

FIVE (Fabbrica Italiana Veicoli Elettrici)

is an Italian innovative start-up incorporated in 2012, leader in the production of electric bikes and motorbikes and controlled by the Italian group Termal. The company decided to move back its manufacturing activities from Shanghai (China) back to Bologna (Italy). FIVE has invested EUR 12 million on 22 May 2017 for a new production plant to be located in Bologna (Italy). Fabio Giatti, the company CEO, stated that the main **motivation for reshoring has been quality**. FIVE was never able to achieve the quality needed for Italian and European consumers after it established with the plant in China. Secondary reasons have been an increase in production costs, the long transportation time, and the made-in effect, since the product could not be considered as made-in-Italy after offshoring. The new plant is expected to operate at full capacity within the next three years by producing a total of 2,500 units in 2017, which is about 30% of FIVE's product portfolio. In this way, FIVE could gradually withdraw production activities at two factories in Shanghai (China), where 50 workers are employed. By 2021, the same number of employees will be active in the new Italian plant.

Turolla

is an Italian producer of motor gear products and fan drive systems. Despite the cost advantage coming from lower labor costs (-35%) in Slovakia, the company plans to reshore its entire Slovakian production to a new plant in Castel San Pietro, Emilia Romagna, in Northern Italy. The Italian plant has been active since June 2017. Its General Manager, Riccardo Carra stated the local network of trained engineers, and the presence of high quality research centres and universities in proximity to the new Italian plant will compensate for the disadvantage of the Italian bureaucracy, which remains however the main disadvantage of the operation. The new plant will not hire new employees at the beginning, directly on site. There are plans of a large scale recruitment of highly competent professionals in the near future, but at the group level, as reported by the Danfoss Group, controller of Turolla.

APPENDIX II

Table II.1 Geographic coverage of the Italian sample of firms

Region	N. of firms
Abruzzo	6,912
Basilicata	2,484
Calabria	6,642
Campania	26,200
Emilia-Romagna	28,920
Friuli-Venezia Giulia	6,164
Lazio	45,923
Liguria	6,900
Lombardia	69,714
Marche	9,041
Molise	1,482
Piemonte	19,075
Puglia	17,255
Sardegna	6,949
Sicilia	18,505
Toscana	22,927
Trentino-Alto Adige	6,562
Umbria	4,574
Valle D'Aosta	721
Veneto	29,864
Total	**336,814**

TableII.2 Premia on manufacturing vs services, foreign vs domestic firms in value added content

Dependent variable: value added content	OLS
domestic firm	-.071***
	(.011)
manufacturing firm	-.035**
	(.012)
domestic & manufacturing firm	.093***
	(.014)
(log of) capital intensity	-.016
	(.014)
(log of) size	-.024***
	(.006)
Constant	1.001***
	(.067)
Adj R squared	0.5506
N. observations	336,814
Industry fixed effects	Yes
Errors clustered by industry	Yes

APPENDIX III

Table III.1 Service robots' classification for personal and non-commercial use

Service robots for personal/domestic use
Robots for domestic tasks
Robot companions/assistants/humanoids Vacuuming, floor cleaning Lawn-mowing Pool cleaning /window cleaning
Entertainment robots
Toy/hobby robots Multimedia/remote presence Education and research Others
Elderly and handicap assistance
Robotized wheelchairs Personal aids and assistive devices Other assistance functions
Personal transportation (AGV for persons) Home security & surveillance Other Personal / domestic robots

Source: International Federation of Robotics, 2016

Table III.2 Service robots' classification for professional and commercial use

Service robots for professional use
Field robotics
Agriculture / Other field robotics
Milking robots
Other robots for livestock farming
Forestry and silviculture
Mining robots
Space robots
Professional cleaning
Floor cleaning
Window and wall cleaning (incl. wall climbing robots)
Tank, tube and pipe cleaning
Hull cleaning (aircraft vehicles etc.)
Other cleaning tasks
Inspection and maintenance systems
Facilities, plants
Tank, tubes, pipes and sewers
Other inspection and maintenance systems
Construction and demolishing
Nuclear demolition & dismantling
Building construction
Robots for heavy/civil construction
Other construction and demolition systems
Logistics systems
Automated guided (AGV) vehicles manufacturing environments /non-manufacturing environments (indoor)
Cargo handling, outdoor logistics
Other logistic systems

Service robots for professional use
Medical robots
Diagnostic systems
Robot assisted surgery or therapy
Rehabilitation systems
Other medical robots
Rescue and security applications
Fire and disaster fighting robots
Surveillance / security robots
Other rescue and security robots
Defence applications
Demining robots
Unmanned aerial vehicles
Unmanned ground based vehicles
Unmanned underwater vehicles
Other defense applications
Underwater systems (civil / general use)
Powered Human
Exoskeletons
Unmanned aerial vehicles (general use)
Mobile Platforms in general use
Underwater systems (civil / general use)
Hotel & restaurant robots
Mobile guidance, information robots
Robots in marketing
Robot joy rides
Others (i.e. library robots)
Other professional service robots not specified above

Source: International Federation of Robotics (2016)

Table III.3 Other Japanese robotics suppliers

Company	Main technology focus	Total revenue in 2016	Market capitalization	Revenue by sector in 2016
Daifuku	Logistics automation systems (automated rack systems, sorting and picking systems), semiconductor and LCD fab cleanroom automation systems (AMHS), airport baggage handling systems.	¥336.1bn	$2.1 bn	31% of revenues are from the electronics sector, 19% are from the automotive sector.
Nidec Sankyo	LCD glass handling robots, semiconductor wafer transport robots, associated controllers, RoboTech (precision reduction gears /reducers), motors, reducers	¥123.3bn	$27.4 bn	20% of the revenues are from robot sales to various sectors
Nachi-Fujikoshi	Spot-welding, arc-welding, handling robots, palletising robots (especially six-axis robots capable of heavier payloads), cutting tools	¥20bn	$0.9bn	Robots are the key revenue drivers, mainly supplies to the automotive industry
Yamaha Motor	SCARA, Cartesian and single-axis robots, pick and place machines, unmanned aircraft used for crop-dusting, SMT equipment, drones	¥48bn	$7.0bn	About ¥20bn from the sales of pick-and-place machines, ¥15-20bn from robots and about ¥5bn from unmanned helicopters
Panasonic	Industrial robots and welding and cutting systems, inspection equipment and screen printers, SMT equipment, sensors, drivers	¥1,052bn	$25.6bn	Industrial robot revenues are between ¥10-20bn
Seiko Epson	SCARA robots, six-axis robots, linear robots, robot controllers. Supplies mainly for automotive and electronics	¥48bn	$6.8bn	Robotics solutions revenue is ¥15.4bn

Company	Main technology focus	Total revenue in 2016	Market capitalization	Revenue by sector in 2016
Mitsubishi Electric	Robots, automation controllers (numerical controls, programmable logic controllers/sequencers), drives (servomotors and inverters), laser cutting	¥540bn	$27.2bn	Robot revenues are at ~¥10bn (US$100m) per year
Hirata	Assembly lines for the automotive sector, and cleanroom robots and loadports for the semiconductor production equipment and LCD panel production equipment industries	¥53bn	$0.7bn	¥20bn from semiconductor equipment (likely including ¥5-10bn from cleanroom robots) and ¥20bn from automation solutions for the automotive industry
Omron	Sensing devices, automation controllers and safety products, robots for light assembly and packaging applications, including SCARA robots, delta robots and six-axis robot arms	¥6bn	$7.7 bn	Omron is integrating the robots with its sensor, safety components, NX/NJ-series automation controllers and the Sysmac automation platform, to offer easy-to-implement solutions to a range of industries – including food processing and pharmaceuticals
Nabtesco	Precision reduction gears (reducers) for industrial robot joints.	¥55.3bn	$3.5bn	Has 60% of the global market share for precision reduction gears for industrial robot joint. 23% of its revenue and 35% of its operating profit are from its precision reduction gears segment; supplies to all the key global industrial robot manufacturers such as Fanuc, Yaskawa, Kuka and ABB

Company	Main technology focus	Total revenue in 2016	Market capitalization	Revenue by sector in 2016
THK	linear motion guides and linear motors	Targets to ¥262bn in 2017	$2.5 bn	About 50% of the worldwide market share in linear motion guides
SMC	precision pneumatic components and systems for semiconductor production equipment, machine tools and other equipment.	Targets to ¥450bn in 2017	$19.9bn	-
Keyence	machine vision solutions, major supplier of other FA components and systems (controls, safety devices, laser marking equipment and barcode readers)	¥379.3bn	$44.2bn	-

Source: compiled from the EU-Japan Centre for Industrial Cooperation (2015)

Table III.4 Summary of key country level finding[34]

Country	USA[35]	GER[36]	FR[37]	ITA[38]	UK[39]	JPN[40]	CHI[41]	KOR[42]	EU[43]
IFR 2016 rank, by 2015 robot sales (% change from 2014)	4 (5%)	5 (0.2%)	NA (3%)	7 (7%)	NA	3 (20%)	1 (29%)	2 (55%)	
IFR 2016 robot density in manufacturing per 10,000 employees	176	301	NA	155	NA	305	49	531	
Primary industry association	Robotics Industries Association	The Mechanical Engineering Industry Association	SYROBO Group	UCIMU-Sistemi per produrre	The British Automation & Robot Association	Japan Robot Association	China Robot Industry Alliance	Korean Association of Robot Industry	
Key public stakeholders	US Department of Defense	German Ministry of Economy and Research	French Ministry of Economy	Italian Ministry of Economic Development	Engineering and Physical Sciences Research Council	Ministry of Economy, Trade, and Industry	PRC State Council	Korean Ministry of Trade, Industry, and Energy	FP for Research and Innovation
Primary robotics programme	Advanced Robotics Manufacturing (ARM) Program	Industrie 4.0 Programme	Industry of the Future Programme	Industria 4.0	State-sponsored research	Robot Revolution Initiative	Made in China 2025	State-sponsored research	Horizon 2020
Programme start	2017	2013	2015	2016	2015	2015	2015	2016	2014
Programme end	NA	2020	2017	2020	NA	NA	2020	2020	2020
Programme component for domestic market creation	Y	N	N	N	N	Y	Y	Y	
Focus robotics sub-fields	aerospace	MFG	MFG	MFG	MFG	agriculture	MFG	medical and rehabilitation	
	automotive					infrastructure and disaster response	service	unmanned robotics	
	composites					manufacturing	social works	social works	
	logistics					medical and rehabilitation		security	
	textiles					service			

* Programme is mostly a combination of financing streams and tax credits for qualified participants.

[35] Funding data retrieved from the United States Department of Defense (US DoD) Jan. 13, 2017 Press Release on ARM Program.

[36] Funding data retrieved from various sources: Temperton (2015), Alpenia (2016), and Thomas (2017).

[37] Funding data retrieved from the French Ministry of Economy's Press Release on the 'Industry of the Future plan (link). The '2.1 billion EUR' value is the one wherein robotics is explicit mentioned.

[38] Funding data retrieved from the Italian Ministry of Economy presentation on 'Industria 4.0'. The value is the overall public finance burden of the Industria 4.0 plan.

[39] Funding data retrieved from the UK-RAS whitepaper on Industrial Automation.

[40] Funding data retrieved from the Japanese Ministry of Economy, Trade, and Industry (METI)'s Press Release on the Japan Robot Revolution Initiative.

[41] No concrete funding data is available regarding Chinese commitment.

[42] Funding data retrieved from the Yonhap News Agency (2017).

[43] Funding data for the robotics-centred EU SPARC project (under Horizon 2020) is the one used as proxy for the program commitment to robotics..

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