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Measuring Innovation in the Autonomous Vehicle Technology

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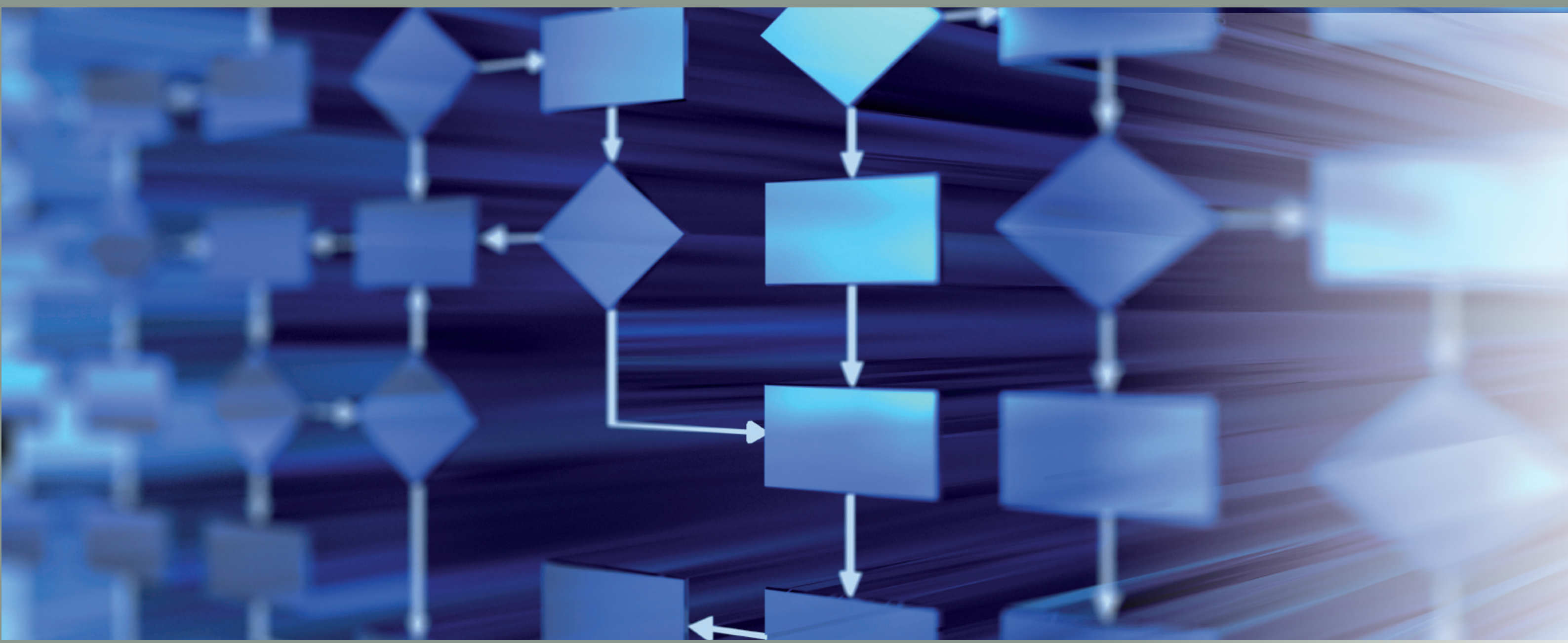

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Abstract

Automotive industry is going through a technological shock. Multiple intertwined technological advances (autonomous vehicle, connect vehicles and mobility-as-a-Service) are creating new rules for an industry that had not changed its way of doing business for almost a century. Key players from the tech and traditional automobile sectors – although with different incentives – are pooling resources to realize the goal of self-driving cars. AV innovation by auto and tech companies' innovation is still largely home based, however, there is some shifting geography at the margin. AV and other related technologies are broadening the automotive innovation landscape, with several IT-focused hotspots – which traditionally were not at the center of automotive innovation – gaining prominence.

JEL codes: O33, O34, L62

Keywords: Autonomous vehicle, Technological change, Innovation geography, Intellectual property

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Introduction

The automotive industry is no stranger to technological waves throughout its history; from steam to internal combustion engines (ICE) and in the more recent years; electric engines. Today, at least four concurrent new technological paradigms are afoot in the automotive industry; Autonomous Vehicles (AVs)[i], connected cars, personal mobility services and Electric Vehicles (EVs).

The focus of this paper is on Autonomous Vehicles (AV) and the challenges that emergence of this technology has introduced to the industry. It is yet to be determined whether AV will revolutionize the auto industry or it is just an echo of familiar changes that the automakers have seen before.

The AV industry is still in its infancy and fully autonomous vehicles are years from being mainstreamed. Nevertheless, robotics and AI are already reshaping the car industry – so much so that new technologies are posing a significant existential threat to the incumbent automakers. AI, data analytics and a slew of connected devices and components are reformulating the industry's business model toward services and the so-called "platform economy".

Traditional automakers fear being supplanted and reduced to bit-players in their core competency – the making and marketing of cars. To tackle these challenges a menu of options is available to them – from investing in internal knowledge development[ii], recruiting human capital[iii] and strategic alliances[iv], to acquisitions of new entrants[v], or a combination of these[vi]. It is not clear which single or combination of the above strategies will yield the most successful results. What is clear though is that neither the incumbents nor the new entrants, on their own, currently have all the required competencies for producing AVs. They either need to join forces or else develop internally the respective skills they now lack.

Against this background, this paper seeks to analyze current innovation in the automotive industry and understand how AV is affecting the geographical spread and concentration of innovation (see Chapter 1 *World Intellectual Property Report (WIPR) 2019*). Understanding the relationship between the new entrants and the incumbents can offer pointers to the evolution of current innovation clusters. How firms react to AV technology will determine which firms will be the market leaders, and which regions will be the AV technological hubs.

In the following sections, the paper starts with explaining the search strategy for identifying and capturing patent and scientific publications that are related to AV, followed by discussing the automotive industry evolution and briefly describes two other related technologies: mobility and connectivity. Next, it explores the impact of AV technology on the automotive industry from two perspectives. First, whether AV technology is changing the nature of innovative collaborations between and within incumbents and entrants. Second, whether it is changing the geography of innovation. In doing so, it discusses in details about geography of innovation in selected auto and tech companies. It concludes with a discussion on potential positive and negative impacts of AV.

1 Search strategy of patents and scientific publication in AV technology

Patents

The AV industry is a combination of various technologies applied to a specific use – automating the operation of ground-based vehicles. Thus, search strategies to identify AV-related technologies and scholarship are inherently imprecise and require creativity and several iterations. Defining clear-cut boundaries is very difficult.

Against these limitations, the paper makes use of technological codes of Cooperative Patent Classification (CPC), an international system for classifying patent documents. A list of CPC classes that corresponds to the technologies used in AV was compiled. The list was divided into two groups. First, the smaller number of niche classes where it is relatively safe to say the entirety were relevant to AV. Second, the classes that were broader and had patents that may not be relevant to AV. For this second group, a list of keywords was added to the search. These keywords were some permutation of autonomous vehicle, car, lorry, etc. These keywords were used to identify the patents that belonged to the selected CPCs and had one of these keywords mentioned either in their patent abstract or title.

The same exercise was repeated with The International Patent Classification (IPC). The relationship between CPC and IPC is that CPC is the Cooperative Patent Classification scheme used by the European Patent Office (EPO) and the United States Patent and Trademark Office (USPTO), which was jointly developed by the two Offices based in a large part on the existing European Classification System (ECLA) and on the USPC, respectively. It is based on the IPC, but it is much more detailed. CPC classification codes can be used to carry out searches on both the Espacenet and the USPTO Classification databases. The more detailed subdivisions of CPC also serve as a source for the revision of the IPC.

Table 1 in the annex, lists the CPC and IPC codes used in the various queries and indicates whether they were used in combination with any keywords or not. The exact keywords used in each case are also listed. Note that query was not case sensitive and plural version of the keywords when applicable were included.

Scientific publications

A query[2] (Q1) has been run on the abstract table of Web of Science (WoS) based on the core keywords provided by CAR group Table 1. A total of ~ 1,200 articles were identified.

These articles were then joined with the Keyword table[3] of WoS. From this exercise the list of most frequent keywords appearing in those 1200 articles were identified and sorted. A total of more than 2,500 unique keywords (tags) were identified. A manual and one-by-one search was conducted on this list. Based on frequency and relevance a secondary list of 40 tags (e.g. predictive cruise control) has been selected and compiled. Table 2 (in the annex) includes this list.

Another query (Q2) based on these additional keyword was ran over the abstracts in the WoS. The result were ~8,000 articles. These articles were then joined with the subject table of WoS. The articles were sorted by subject and frequency. After eyeballing for false positives, articles which were in subjects included in Table 3 (in the annex) were eliminated. After this cleaning exercise ~ 6,000 articles remained in the final sample used for first round of data analysis.

[2] The query included the plural and the regex format of these keywords. Queries in Heidi SQL are not case sensitive.

[3] Please note that the Keyword table in the WoS includes the keywords that are inserted by the authors themselves as tags in the articles and should not be confused with the keywords used in table 2.

Table 1

Core Keywords in query Q1

	Vehicle	Car	Truck	Taxi	Shuttle	Lorry	Driving	Transport(ation)	Automobile
Automated	X	X	X	X	X	X	X	X	X
Autonomous	X	X	X	X	X	X	X	X	X
Self-driving	X	X	X	X	X	X		X	X
Driverless	X	X	X	X	X	X		X	X
Unmanned	X	X	X	X	X	X		X	X
Robotic	X	X	X	X	X	X	X	X	X
Pilotless	X	X	X	X	X	X	X	X	X
Unpiloted	X	X	X	X	X	X	X	X	X

2 Technological evolution of the automotive industry

Industry evolution literature[vii] divides the life cycle of any given industry into five stages: the introductory embryonic stage, growth, shakeout, maturing and decline. The early stages are ripe with high uncertainty and numerous entries and exits. Later on, the emergence of a dominant design will leave only a handful of firms standing. Names like Sprite, Unito, Wolfe, Angus, Empire do not exactly ring a bell and that is because these early car companies were some of the thousands that exited the industry more than a century ago when the first automobiles started mesmerizing the world.

Until a few years ago, the automotive sector was considered a mature industry with well-established players and for which the key technological questions had been answered in the 1930s.[viii] The initial innovations were fundamental as they defined the basic structure of the automobile. These included the development of water-cooled engines placed in the front of the car, shaft-driven transmissions, streamlined bodies and pressed steel frames.[ix]
The remaining product and process innovation in the years after the Second World War, and particularly after the 1970s, was attributed to rising oil prices, cost pressure arising from intensifying international competition and changes in consumer demands.

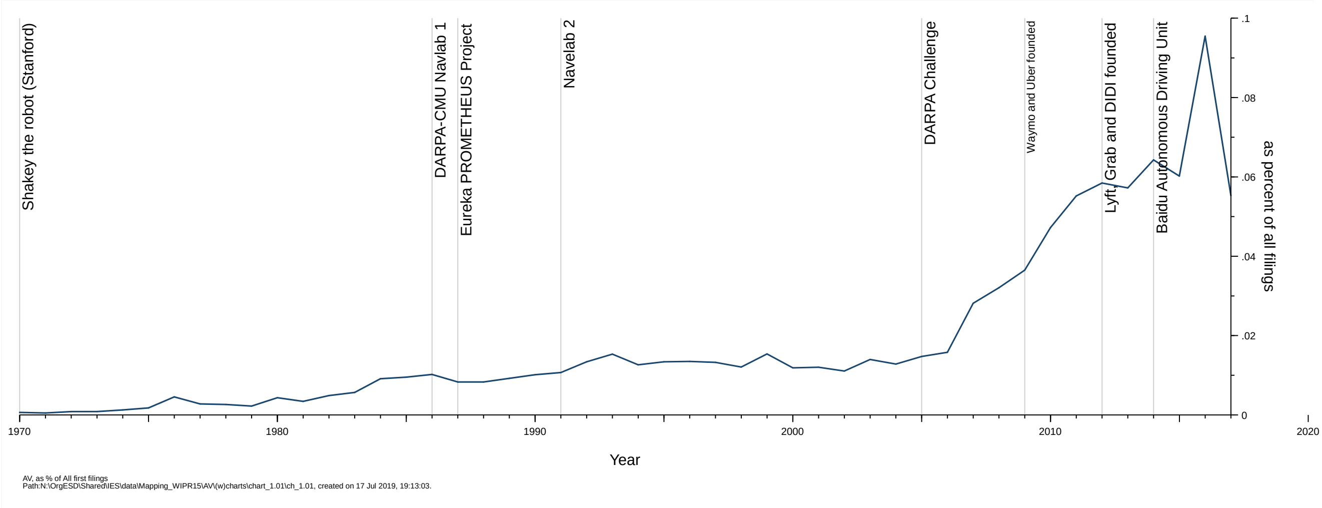
At the turn of the millennium this picture changed; the increasing processing power of computers in conjunction with the widespread adoption of the internet and, consequently, smartphones, opened several avenues for innovation. Many established old-line industries – like newspapers, the music business, TV and retail – woke up to the waves of technological disruption that advances in software and the hardware side of computer technology had triggered. These affected not only their core competencies, but also their complementary assets – those needed to commercialize and market products – and their distribution channels. Many of these industries were rattled and reshuffled by the digital era.
The automotive industry – although with some lag – has not been untouched by the waves. For instance, in 2018, the global electric vehicle fleet exceeded 5.1 million,[x] achieving almost 2.1 percent of market share. This number is expected to increase to around 30 percent by 2030.

An increasing trend in innovative activity in AV technology is observed in the mid-2000s with a major innovative spike after 2010. Despite this upward trend, AV technology is still very niche and comprises less than 0.1 percent of total patent filings globally even at the height of that spike in 2016 (see Figure 1).

Figure 1

AV technology has taken off since mid-2000s

AV share of all patent first filings and key milestones over time



Source: WIPO based on PATSTAT and PCT data (see section1 and Technical Notes WIPR 2019).

Industry life-cycle literature discusses how industries, as they reach maturity, are subject to new technological shocks which can be the seeds for the beginning of a new cycle. Whether the new cycle is actually realized or not depends on the existence of various technological and non-technological competencies. The participants in the new cycle may be from within the same industry or from previously non-competing industries whose competencies meet the technological requirements for entering the new cycle.

Competencies required for the development of AVs have allowed players from the tech industry to enter the automotive sector, with the ultimate goal of creating fully autonomous vehicles that require no driver. The main ingredients for the realization of AVs are both the "V" and the "A." An AV unit is basically chassis and engine, plus an intelligence that brings full autonomy to the physical aspect. The incumbent automakers' core competency[xi] lies with the "V." Creating all the software (e.g., artificial intelligence) and hardware elements (e.g., sensors and cameras) required for autonomy – the "A" – is within the core competencies of the tech companies.

The incumbent automakers' core competencies are mass manufacturing, mechanical engineering and jumping through the thousands of regulatory hoops that lead to the final car being on the road. They are the result of decades of accumulated tacit knowledge – knowledge that is not easily replicable – and know-how. Mastering these competencies is not immediate and straightforward.

New entrants' technological competencies are in hardware and software, especially the deep-learning and real-time control algorithms needed for vehicle autonomy. They are beyond the spectrum of expertise of most automakers and their suppliers, which have little prior knowledge of them.

Core competencies of the automakers are more or less familiar to most people, but not so the technological waves that are transforming the industry. The following sections will briefly discuss two technological waves that are somewhat related. Electric vehicles, although equally affecting the industry, is not within the focus and scope of this paper.

Mobility as a service

Parallel to these efforts, Mobility-as-a-Service (MaaS), which integrates various transport services into a single service available on demand, became a popular concept. Companies like Uber (founded in 2009) and Lyft (founded in 2012) in the United States of America (U.S.) came to fruition. Soon, others with similar business models started popping up all around the globe: Ola Cabs in India (founded in 2010), Grab (founded in 2012) in Singapore and DiDi Chuxing (founded in 2012) in China. These companies provided services like ride-hailing and/or car-sharing. Many of them have expanded their businesses to other services, including deliveries, logistics and bike-sharing.

Uber's former CEO, Travis Kalanick, described the development of "robotaxis" (self-driving taxis) as "existential" to the company. If the future of automobiles is driverless, mobility companies have a vested interest in AV technology for multiple reasons. First, removing the driver from the equation will reduce their costs.

Second, their business model has the potential to change the economics of the automotive industry. The MaaS business model can lead to a reduction of private car ownership and a shift to a more fleet-oriented system, where the revenue model would be based on mileage instead of the number of cars sold. AV technology can enable a system where people buy access to transportation as opposed to owning vehicles. A rough calculation based on the number of cars on the road and their average annual mileage, compared to what mobility companies charge per mile, shows that if all existing cars were to convert to AVs, automakers could make a profit and charge far less than mobility companies.

Third, mobility companies are sitting on abundant data and information about customer behavior and preferences, which would give them a significant advantage in a sales environment that is increasingly about customized and bespoke experience.

Connected vehicles

Another branch of technology that has intertwined with autonomous driving is "connected vehicle technology." A vehicle can be connected without being autonomous, therefore the two terms are not interchangeable and should not be confused. The connected vehicle technologies allow vehicles to communicate with each other and the world around them. They aim to increase efficiency and road safety for both drivers and pedestrians. Popular use cases for connected vehicles are sharing braking data, real-time high-definition maps, road hazards, closure updates, fleet tracking and infotainment. All of these require minimum latency (delay in implementation of commands) and maximum precision in the transmission of data. That is why 5G cellular network technology is becoming the future of autonomous and "connected" vehicles.[xii] Several tech companies, notably Huawei, Intel and Ericson, are exploring this field.

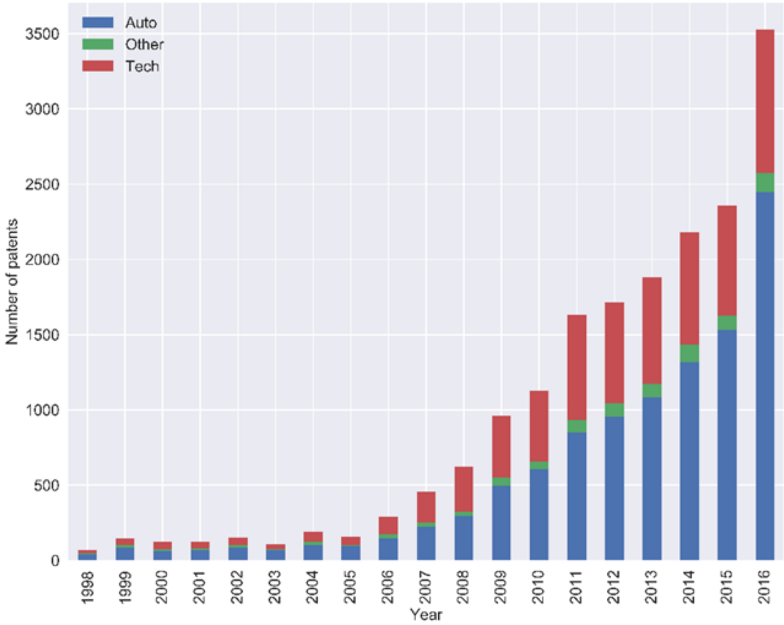
3 Technological shift

The sectoral breakdown of AV patenting over time supports the idea that the rise of AI, robotics and mobility services is the main driver of the technological shift. In the years immediately after 2005 almost half of the patents seem to be from the tech sector.[xiii] However, the traditional auto sector later regained dominance (see Figures 2 and 3).
Not surprisingly, the majority of the patent applicants are companies, roughly 20 percent are individuals and only 10 percent are universities or other public entities.

Figure 2

Rise of AI, robotics and mobility services is the main driver of the technological shift in the mid-2000s

Sectoral breakdown of AV-related patents by frequency

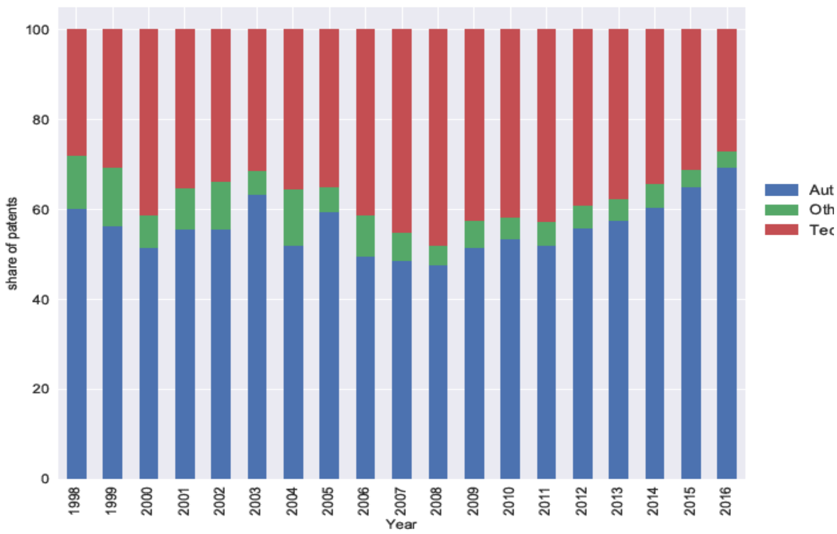


Source: WIPO based on PATSTAT and PCT data (see section1 and Technical Notes WIPR 2019).

Figure 3

In the years immediately after 2005 the tech sector comprises almost half of the patents in AV

Sectoral breakdown of AV-related patents by share



Source: WIPO based on PATSTAT and PCT data (see section1 and Technical Notes WIPR 2019).

A quick look at the list of the top applicants (see Table 5 in the annex) in the 1990s shows mostly auto companies. Later (see Table 6 in the annex) lists tell a different story. Google, Qualcomm, Mobileye, Uber, Baidu are not among the usual suspects of the auto industry, but from the mid-2010s they appear in the top 100 AV patent applicants. These top 100 applicants (see table 4 in the annex), led by names such as Ford, Toyota and Bosch have generated around half of the total patents. Non-automakers also feature in the list of top patent applicants. Google and its AV subsidiary Waymo lie in top ten position, with more than150 patents, ahead of automakers like Nissan, BMW and Hyundai. They are followed by other companies like Uber and Delphi, which each have around 60 AV patents and are ranked joint 30th.

4 Collaboration among auto companies

In the face of the AV technological shock, auto companies have an incentive to join forces to share the costs and risks but also defend their market position, which is being threatened by outsiders. The common threat they are facing is "commoditization" of their core competency; that is, becoming simply a supplier of a commodity good, which in this case is a car. The tech companies would be the ones generating the value added and therefore reaping the largest benefits. Global automakers Daimler and BMW announced they would partner in a new long-term partnership to co-develop automated driving technologies. The joint effort will involve 1,200 technicians from both companies. The technicians will be based at BMW's autonomous driving campus in Unterschleissheim, near Munich, its Mercedes subsidiary's technology center in Sindelfingen, near Stuttgart, and Daimler's testing and technology center in Immendingen in southern Germany. The two companies aim to launch their next generation, self-driving passenger cars by 2024.[xiv] Audi, another German automaker, has announced that it is to join forces with them.[xv]

While some may be surprised to see long-time foes becoming friends, it's not rare in AV development. The enormous costs of designing and building computer-powered vehicles has already prompted Honda to pool its efforts with General Motors, while Volkswagen is pursuing talks with Ford about an alliance on autonomous cars.

Collaboration among tech companies

Tech firms also would need to collaborate with each other to share the technology's large risks and costs. Most tech firms, especially the smaller startups, occupy niches, focusing on hardware, software, mobility services, connectivity, communications and many more. With the exception of Waymo – which develops all its hardware and software stack[xvi] in-house – no single tech company has the necessary expertise in all these areas. So, collaboration among tech companies is not uncommon. Taiwan-based VIA Technologies Inc. announced in 2018 that it is partnering with AI vision startup Lucid to deliver AI-based depth sensing in dual-and multi-camera devices for use in security, retail, robotics and autonomous vehicles.[xvii] This is just one of a long list of examples of collaboration between tech companies.

Some tech companies have also decided to give open access – free of cost or other access barriers – to their closely guarded data and technologies. For instance, Waymo has decide to sell one of its three LIDAR sensors – called Laser Bear Honeycomb, which uses a laser to measure distances – to third parties interested in using the technology for purposes other than self-driving cars. Some believe the LIDAR sensor development curve is similar to Moore's Law in computer chips – every 18 months, resolution will double and the price drop by half[xviii] – so granting open access offers the chance to scale up with reduced costs.

Waymo is making some of the high-resolution sensor data gathered by its fleet of autonomous vehicles available to researchers for free. It isn't the first company to release an open dataset. In March 2019, global technology company Aptiv was one of the first large AV operators to publicly release a set of its sensor data. Uber and Cruise, the autonomous division of General Motors, have also released their AV visualization tools to the public.[xix]

These decisions are in line with the "open innovation"[xx] strategies that firms adopt as a response to highly complex innovative ideas.

Collaboration between tech and auto companies

AV technology is not rendering the upstream core knowledge of automakers completely obsolete. In fact – at least for now – AV is a type of technological discontinuity that needs the incumbent's core competency to achieve its goal. Research shows[xxi] that – historically – incumbents can survive the discontinuity if they cooperate with the entrants challenging their core knowledge. In presence of strong "appropriability regimes," the new entrants have the incentive to license out their technologies. The literature[xxii] defines strong appropriability regimes as environmental factors – legal protection (e.g., patents) or the needed knowledge is difficult to pass on (tacit) or codified – that allow the tech company to recuperate its investment.

AV technology shows characteristics of strong appropriability. This allows the new entrants to cooperate with incumbents while securing their benefits without fear of imitation.[xxiii] By partnering with tech companies, automakers gain a better understanding of the key technologies that are transforming the industry and accelerate the learning process that can keep them competitive in a rapidly changing environment.

While it seems logical for auto companies to collaborate with tech companies, the reverse is not so straightforward. Some might even argue that tech giants do not need auto companies and that they can, and will eventually, directly enter the auto sector.[xxiv] Their argument focuses on the costs. Since IT giants like Alphabet, Amazon and Apple in the U.S. and Alibaba, Baidu and Tencent in China have deep pockets they can easily afford the costs of designing and manufacturing a car. Others do not agree.[xxv] Excelling at complex mass manufacturing, organizing quality value chains, dealing with complex regulatory issues is neither trivial nor negligible. U.S. energy and automotive company Tesla's financial losses and struggles to keep up with delivery schedules of its Model 3 electric sedan car attest to this issue. The ecosystem in which automakers operate and lobby is their stronghold. Even if the tech companies had the technological capacity to produce cars, they would still have difficulties challenging the current socio-technical regime unless they collaborate with the incumbent automakers.

Therefore, tech companies also have an incentive to collaborate and see where their strengths complement those of the automakers. This division of labor, at least at this stage of the industry, allows each side to focus on what they do best and is the shortest and safest route to AV success.

The types of collaboration outlined are not mutually exclusive and they coexist. The high uncertainty makes firms simultaneously bet on multiple combinations of the three options – "build," "borrow" and "buy."[xxvi]

By default, much of the above collaboration may not be captured by patent or scientific publication data. The main reason is that most are formal partnerships and alliances, joint ventures, investments or acquisitions. Out of more than 100 formal collaborations identified[xxvii], in terms of frequency, the largest share belongs to auto–tech, followed by tech-tech and auto-auto. Finally, a small portion of the collaboration is between tech companies and national or regional government entities. For instance, Detroit-based Quadrobot and the Chinese Postal Service are partnering to produce autonomous delivery vans.

5 Role of geography in AV technology

Spread over time

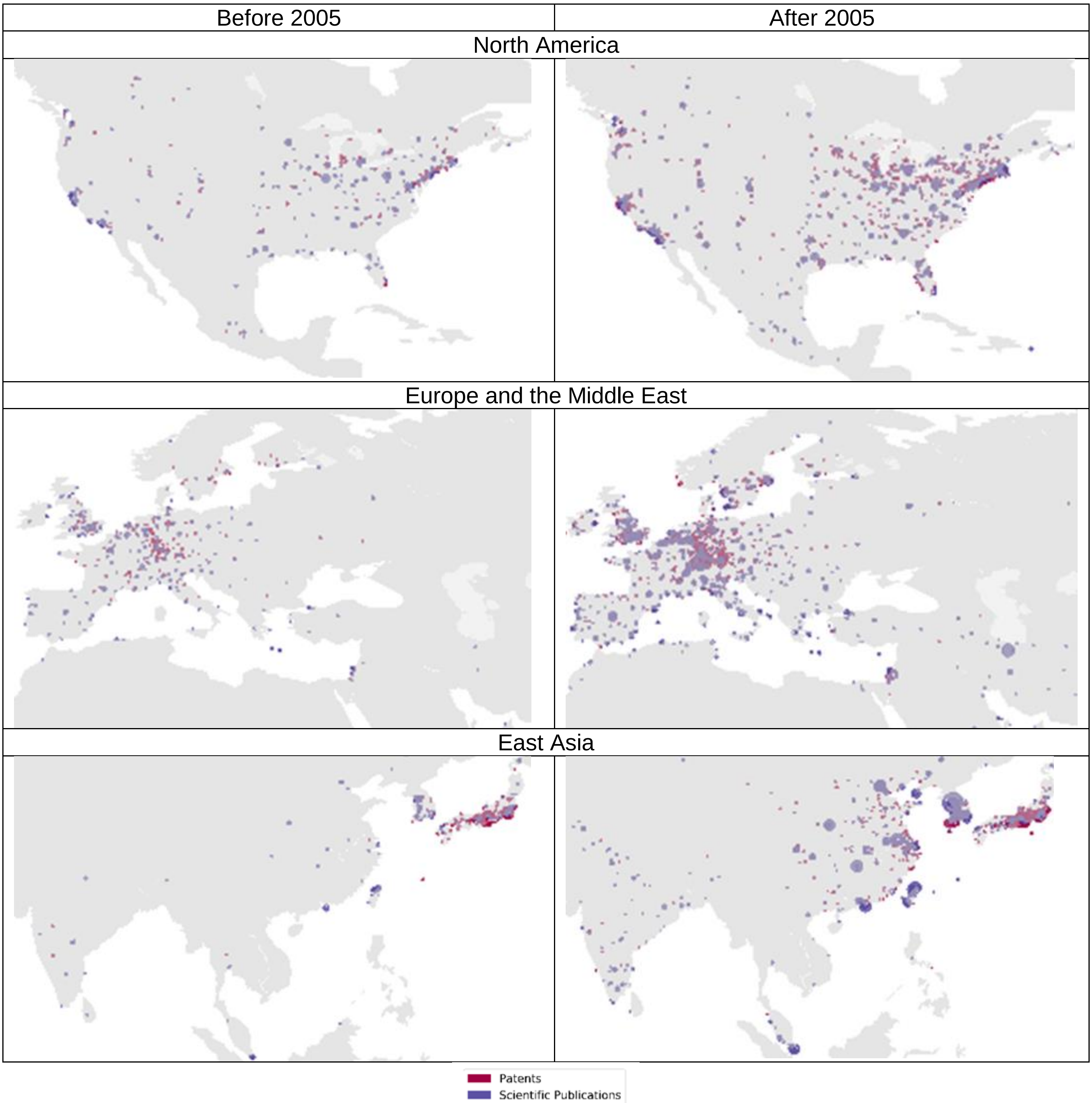
Until a few years ago, no one would have associated places like Boston, San Francisco and Pittsburg, Singapore or Jerusalem with the automotive industry. The more familiar names were Detroit, Toyota City in Japan and Stuttgart in Germany. But advances in robotics and AI as general-purpose technologies[xxviii], with multi-faceted applications in various fields, have created avenues for new entrants. Naturally, these entrants reside in the main tech hubs, such as the U.S. Silicon Valley and others around the world. However, places like Singapore or Jerusalem, with no history in the automotive sector but with booming and vibrant tech and startup scenes, have become highly active in AV technology.

A historical look at innovative activity in AV shows its geographic evolution and global spread. Figure 4 displays the regions involved in patenting[xxix] and publishing scientific articles concerning AV-related technologies, before and after 2005. Not surprisingly, in the earlier period, regions that traditionally led the auto market also show high patenting activity. But even then, there was significant patenting activity from Silicon Valley and Singapore. The focus in the earlier period was still on areas like advanced driver assistance systems (ADAS) and automated highway systems (AHS), technologies that are not directly related to AI/robotics approaches. These patents were closer to the operations of the traditional automobile and mainly related to level[xxx] 1 or 2 of driving automation.

Figure 4

East Asia has become very active in AV technology in the recent years

Geographical distribution of AV-related patents and publication in selected regions



Source: WIPO based on PATSTAT, PCT and Web of Science data (see section1 and Technical Notes WIPR 2019).

In the later years, we observe some developing countries that are not traditional automaking countries also engaging in this technology. The most noticeable change is the emergence of China and India. As discussed earlier, the changing nature of technology can be one explanation of this expansion. The new sets of technologies – AI and robotics – allow for “leapfrogging” of countries/regions with no longstanding ties to the auto-manufacturing sector.[xxxi] Despite this, the top countries involved are still the U.S., Japan, Germany, the Republic of Korea and Sweden, with the U.S. and China latterly being the most active.

When looking at scientific publication we observe that more developing countries in the Middle East, Latin America and Africa – that are not captured in the patenting data – are highly active in generating basic research and scientific articles (see Map 1 in the annex). Iran would be an example of a country highly active in scientific publication but with almost no patenting presence in this field. Scientific publication data complements patents in giving a better picture of the innovation landscape in AV technology.

6 Is AV technology changing the geography of innovation in automotive industry?

Innovation has a geographic dimension.[xxxii] Research has shown that industries tend to co-locate in the vicinity of each other (see Chapters 1 and 2 of WIPR 2019). The two types of players in the auto industry, the incumbents and the new entrants, have their own geographical clusters. The new entrants belong to the tech clusters of the world (e.g., Silicon Valley), whereas the incumbent automakers are well established in their manufacturing clusters (e.g., Detroit). The key question is whether the emergence of AV has made the automakers and tech companies seek greater geographic proximity. If the answer is yes, in which direction? The automakers are appearing in the tech clusters or vice versa.

While it is too early to give a definitive answer to the above questions, evidence based on patent data can shed some light. This section looks at the top global auto industry companies’ patents, selected from three geographic areas: the U.S. (Ford and GM), Germany (Daimler, BMW, Audi, Volkswagen and Bosch) and Japan (Toyota, Honda and Nissan). These companies’ total patent portfolio was examined, and a subset of patents related to AV technology identified and flagged. As customary approach, applicants names were harmonized manually based on similarity of the listed applicant name and address. Particular attention was made in identifying possible name changes overtime. Subsidiaries and/or mergers and acquisitions were not factored into the harmonization process.

Based on this data the share of each company’s total patenting for different clusters is calculated together with that of AV patents. For instance, 72.6 percent of Daimler’s total patents are in Stuttgart, with 76.9 percent of its AV patents also being there.

The major chunk of automakers’ AV patents is still generated in the same main clusters where most of their patenting happens. Nevertheless, there are also important variations. More than 82 percent of Japanese automakers’ total and AV patents belong to their primary, Japan-based clusters, a far higher percentage than that of the two U.S. companies, as can be seen from Tables 2 below.

A quick look at the list below of second-line clusters reveals some interesting differences. A number of clusters, such as San Jose, Pittsburg, Berlin, Los Angeles and Osaka, have strong AV specialization (in the sense that their AV share is large relative to their total patent share). For Volkswagen, for example, San Jose and Berlin each have 16.1 and 9.7 percent of AV patents but only 1 and 4.8 percent, respectively, of general patents.

Table 2

While there is some shifting geography at the margin, auto companies' innovation is still largely home-based**

Audi					
Cluster name	**Country code**	**Total count**	**Total share**	**AV count**	**AV share**
Ingolstadt	DE	4705	60.1	48	60
Noise	XX	2159	27.6	18	22.5
Munich	DE	839	10.7	15	18.8
San Jose-San Francisco	US	30	0.4	5	6.2
Frankfurt	DE	302	3.9	5	6.2
Beijing	CN	32	0.4	3	3.8
Ulm	DE	38	0.5	2	2.5
Stuttgart	DE	729	9.3	2	2.5
Braunschweig	DE	90	1.2	1	1.2

BMW					
Cluster name	**Country code**	**Total count**	**Total share**	**AV count**	**AV share**
Munich	DE	9405	72.5	69	84.1
Noise	XX	3648	28.1	13	15.9
Nürnberg	DE	174	1.3	5	6.1
Würzburg	DE	57	0.4	3	3.7
San Jose-San Francisco	US	47	0.4	3	3.7
Berlin	DE	123	0.9	2	2.4
Frankfurt	DE	413	3.2	1	1.2
Köln-Dusseldorf	DE	312	2.4	1	1.2
Hamburg	DE	76	0.6	1	1.2

Bosch					
Cluster name	**Country code**	**Total count**	**Total share**	**AV count**	**AV share**
Stuttgart	DE	45377	69.1	170	77.6
Noise	XX	14359	21.9	36	16.4
Munich	DE	1688	2.6	11	5
San Jose-San Francisco	US	686	1	10	4.6
Ulm	DE	814	1.2	9	4.1
Braunschweig	DE	358	0.5	9	4.1
Köln-Dusseldorf	DE	1437	2.2	6	2.7
Hannover	DE	966	1.5	6	2.7
Detroit-Ann Arbor	US	556	0.8	6	2.7

Daimler					
Cluster name	**Country code**	**Total count**	**Total share**	**AV count**	**AV share**
Stuttgart	DE	21326	72.6	93	76.9
Noise	XX	4624	15.7	21	17.4
Ulm	DE	1697	5.8	9	7.4
Frankfurt	DE	1485	5.1	5	4.1
Aachen	DE	211	0.7	5	4.1
Horb am Neckar	DE	659	2.2	4	3.3
Biberach an der Riß	DE	91	0.3	3	2.5
Berlin	DE	555	1.9	3	2.5
Munich	DE	1011	3.4	3	2.5

Ford					
Cluster name	**Country code**	**Total count**	**Total share**	**AV count**	**AV share**
Detroit-Ann Arbor	US	11710	63.5	100	69.9
Noise	XX	5878	31.9	52	36.4
Köln-Dusseldorf	DE	1324	7.2	9	6.3
San Jose-San Francisco	US	280	1.5	5	3.5
Chicago	US	187	1	5	3.5
Aachen	DE	591	3.2	4	2.8
New York City	US	597	3.2	3	2.1
Boston	US	350	1.9	3	2.1
Philadelphia	US	163	0.9	3	2.1

GM					
Cluster name	**Country code**	**Total count**	**Total share**	**AV count**	**AV share**
Detroit-Ann Arbor	US	11608	42.5	64	54.2
Noise	XX	10994	40.2	38	32.2
Los Angeles	US	931	3.4	13	11
Waterford*	US	1099	4	12	10.2
Frankfurt	DE	2786	10.2	9	7.6
New York City	US	732	2.7	6	5.1
Pittsburgh	US	53	0.2	6	5.1
Rochester	US	1559	5.7	5	4.2
Boston	US	631	2.3	5	4.2

Honda					
Cluster name	**Country code**	**Total count**	**Total share**	**AV count**	**AV share**
Tokyo	JP	84357	90.8	135	82.3
Noise	XX	3104	3.3	14	8.5
Los Angeles	US	203	0.2	6	3.7
Osaka	JP	2394	2.6	4	2.4
Nagoya	JP	2842	3.1	3	1.8
Columbus	US	475	0.5	3	1.8
San Jose-San Francisco	US	312	0.3	2	1.2
Niihama	JP	30	0	2	1.2
Cleveland	US	13	0	1	0.6

Nissan					
Cluster name	Country code	Total count	Total share	AV count	AV share
Tokyo	JP	81428	97	142	87.7
Osaka	JP	1279	1.5	14	8.6
San Jose-San Francisco	US	32	0	5	3.1
Nagoya	JP	1036	1.2	4	2.5
Noise	XX	950	1.1	2	1.2
Kitakata	JP	304	0.4	1	0.6
Hamamatsu	JP	198	0.2	1	0.6
Shizuoka	JP	68	0.1	1	0.6
Detroit-Ann Arbor	US	46	0.1	1	0.6
Toyota					
Cluster name	Country code	Total count	Total share	AV count	AV share
Nagoya	JP	130077	95.4	343	93.7
Tokyo	JP	7332	5.4	19	5.2
Osaka	JP	3188	2.3	11	3
Shizuoka	JP	232	0.2	4	1.1
Noise	XX	1139	0.8	3	0.8
San Jose-San Francisco	US	76	0.1	3	0.8
Toyohashi	JP	275	0.2	1	0.3
Fukui-shi	JP	82	0.1	1	0.3
Detroit-Ann Arbor	US	58	0	1	0.3
VW					
Cluster name	Country code	Total count	Total share	AV count	AV share
Wolfsburg	DE	5938	47.9	29	46.8
Braunschweig	DE	4594	37.1	25	40.3
Noise	XX	2815	22.7	12	19.4
San Jose-San Francisco	US	127	1	10	16.1
Berlin	DE	600	4.8	6	9.7
Hannover	DE	420	3.4	3	4.8
Hamburg	DE	115	0.9	3	4.8
Munich	DE	255	2.1	2	3.2
Köln-Dusseldorf	DE	300	2.4	2	3.2

* Waterford, Michigan
** The sum of the percentages may be more than 100 percent, due to the fact that a single patent can be assigned to more than one cluster so there is double counting.

In order to test whether tech companies have moved physically closer to automakers, the same exercise was repeated. The selected companies were Google, Waymo, Delphi, Mobileye, DeepMap, Magna Electronics, Qualcomm, Uber and Apple. No systematic trend toward auto clusters was observed (see Table 3). As with automakers, the lion's share of both total and AV patenting happens in the same top cluster.

The geography of Uber's AV patents is interesting. While 39.1 percent of its patents are in San Francisco, Silicon Valley is not its top cluster when it comes to AV. Around 48.5 percent of Uber's AV patents are in Pittsburgh, where it has been hiring and collaborating with CMU researchers. Uber has also been testing AVs in Pittsburg since late 2018.

These results indicate that, while there is some shifting geography at the margin, auto and tech companies' innovation is still largely home based. However, the evidence available, although interesting, should be treated with caution. The numbers, particularly for AV patents, are very limited and the weight of this limited set of patents may distort the overall picture. Moreover, patent data is made public with at least 18 months' delay after being first filed. And the actual innovation may have been developed months, if not years, before the patent request was made. Finally, applicants' name disambiguation issues may have impacted the results for some companies.

Table 3

While there is some shifting geography at the margin, tech companies' innovation is still largely home-based*

Apple					
Cluster name	**Country code**	**Total count**	**Total share**	**AV count**	**AV share**
San Jose-San Francisco	US	6764	59	3	27.3
Noise	XX	2245	19.6	3	27.3
Boston	US	333	2.9	1	9.1
Philadelphia	US	138	1.2	1	9.1
Portland	US	122	1.1	1	9.1
Pittsburgh	US	70	0.6	1	9.1
London	GB	66	0.6	1	9.1
Atlanta	US	61	0.5	1	9.1
New Haven	US	52	0.5	1	9.1
Baidu USA					
Cluster name	**Country code**	**Total count**	**Total share**	**AV count**	**AV share**
San Jose-San Francisco	US	9	50	3	100
Beijing	CN	2	11.1	1	33.3
Noise	XX	4	22.2		
Los Angeles	US	2	11.1		
Seoul	KR	2	11.1		
Elmira	US	2	11.1		
Wuhan	CN	1	5.6		
San Diego	US	1	5.6		
Washington-Baltimore	US	1	5.6		
Deepmap					
Cluster name	**Country code**	**Total count**	**Total share**	**AV count**	**AV share**
Noise	XX	2	50	2	50
Tel Aviv	IL	1	25	1	25
Haifa	IL	1	25	1	25
San Diego	US	1	25	1	25
Pittsburgh	US	1	25	1	25
London	GB	1	25	1	25
Richmond	US	1	25	1	25

Delphi

Cluster name	Country code	Total count	Total share	AV count	AV share
Noise	XX	4368	61.2	15	38.5
Los Angeles	US	95	1.3	9	23.1
San Jose-San Francisco	US	129	1.8	8	20.5
Pittsburgh	US	29	0.4	7	17.9
Salinas	US	13	0.2	5	12.8
Detroit-Ann Harbor	US	1097	15.4	4	10.3
Indianapolis	US	430	6	3	7.7
Akron	US	15	0.2	2	5.1
Dayton	US	449	6.3	2	5.1

Google

Cluster name	Country code	Total count	Total share	AV count	AV share
San Jose-San Francisco	US	6480	54.9	101	94.4
Noise	XX	1951	16.5	5	4.7
Salinas	US	55	0.5	3	2.8
Koblenz	DE	4	0	3	2.8
Seattle	US	438	3.7	1	0.9
Zürich	CH	370	3.1	1	0.9
Washington-Baltimore	US	179	1.5	1	0.9
Cambridge	GB	135	1.1	1	0.9
Seoul	KR	99	0.8	1	0.9

Magna Electronics

Cluster name	Country code	Total count	Total share	AV count	AV share
Noise	XX	167	38.2	39	48.1
Holland	US	34	7.8	21	25.9
Grand Rapids	US	19	4.3	13	16
Tucson	US	12	2.7	11	13.6
San Jose-San Francisco	US	49	11.2	9	11.1
Detroit-Ann Harbor	US	38	8.7	6	7.4
New York City	US	32	7.3	5	6.2
Frankfurt	DE	16	3.7	4	4.9
Philadelphia	US	14	3.2	4	4.9

Mobileye

Cluster name	Country code	Total count	Total share	AV count	AV share
Jerusalem	IL	56	43.8	30	42.3
Noise	XX	30	23.4	18	25.4
Tel Aviv	IL	18	14.1	13	18.3
San Jose-San Francisco	US	7	5.5	5	7
New York City	US	5	3.9	3	4.2
San Diego	US	4	3.1	3	4.2
Philadelphia	US	3	2.3	2	2.8
Detroit-Ann Harbor	US	3	2.3	2	2.8
Phoenix	US	2	1.6	2	2.8

Qualcomm

Cluster name	Country code	Total count	Total share	AV count	AV share
San Diego	US	13242	49.1	32	53.3
Noise	XX	5219	19.3	10	16.7
San Jose-San Francisco	US	3323	12.3	4	6.7
Boston	US	981	3.6	4	6.7
Auckland	NZ	28	0.1	4	6.7
New York City	US	1571	5.8	3	5
Munich	DE	77	0.3	3	5
Chicago	US	367	1.4	2	3.3
Minneapolis	US	325	1.2	2	3.3

Uber

Cluster name	Country code	Total count	Total share	AV count	AV share
Pittsburgh	US	21	13	16	48.5
San Jose-San Francisco	US	63	39.1	10	30.3
Noise	XX	37	23	3	9.1
New York City	US	7	4.3	2	6.1
Tel Aviv	IL	7	4.3	1	3
Los Angeles	US	6	3.7	1	3
Stockholm	SE	2	1.2	1	3
London	GB	2	1.2	1	3
Albuquerque	US	1	0.6	1	3

Waymo

Cluster name	Country code	Total count	Total share	AV count	AV share
San Jose-San Francisco	US	98	81	58	86.6
Noise	XX	10	8.3	4	6
Salinas	US	3	2.5	2	3
Tokyo	JP	4	3.3	1	1.5
Osaka	JP	3	2.5	1	1.5
Zürich	CH	2	1.7	1	1.5
Cambridge	GB	1	0.8	1	1.5
Vancouver	CA	1	0.8	1	1.5
Rochester	US	1	0.8	1	1.5

* The sum of the percentages may be more than 100 percent, due to the fact that a single patent can be assigned to more than one cluster so there is double counting.

7 Potential positive and negative impacts of AVs

Despite the high anticipation that surrounds them, fully autonomous vehicles are, if not decades, definitely years away.[xxxiii] Multiple intertwined technological advances are creating new rules for an industry that had not changed its way of doing business for almost a century. Key players from the tech and traditional automobile sectors – although with different incentives – are pooling resources to realize the goal of self-driving cars. However, the obstacles are not simply technical. Every technological shock at the early stages faces some level of socio-technical inertia in the sense that new technology requires organizational changes that also affect the interaction of people and technology. Often times, change is not easily welcomed.

The current ecosystem of the automotive industry – its market power and its social and political position, for example – has been in place for decades and is very strong. This ecosystem is not so likely to change easily unless the key players in the industry change (i.e. existing automakers exit the market or the market is totally taken over by the tech companies), there is a drastic transformation of policy and regulatory issues or customer demand and preferences shift considerably. At the same time, public opinion is still split over AV.

Advocates of AV technology see it solving several grave urban problems. For example, it could reduce traffic jams and air pollution and improve road safety. Increased precision in the movement of vehicles and the elimination of human error can reduce traffic fatalities. Connected "smart" vehicles can safely travel much closer together – a technique known as "platooning." This, together with automated highway systems, should increase road capacity and lead to other efficiency gains, such as lower fuel consumption and better energy efficiency, which will also have a positive impact on the environment.

Hours would no longer be wasted "behind the wheel" and those who would once have been driving could instead dedicate time to relaxing, working or even sleeping. Children, senior citizens and disabled people would have more independence and mobility. Land currently devoted to parking lots could be put to other uses.

Not everyone is so positive about self-drive cars, however. In 2018, the death of a cyclist in Arizona in an accident involving a test vehicle operating in self-driving mode was a huge setback. Some companies temporarily halted road testing. Whatever the state of play technologically, the general public may not yet be ready for AVs to go mainstream. Some critics question whether AVs would really help solve urban issues such as traffic jams and pollution. The new technology could simply increase the number of vehicles on the road, and therefore congestion. And with cars being self-driving, commuters might be prepared to "drive" further to work rather than take a train, which is less polluting.

Privacy and cyber-security are also major concerns. Data about drivers collected through autonomous, connected vehicles and other "intelligent transport system" applications could potentially be used for purposes not related to driving. The ability of hackers to crack the system, and alter information or the identity of another vehicle is one of the many serious security worries. Legal and regulatory systems already have trouble keeping up with the fast pace of change in the automotive industry. It is still not clear, in the case of an accident, who would be legally liable – the company that runs the software system, the hardware or the mobility platform.

Moreover, countries and regions are at different levels of infrastructure readiness for AVs. Uneven degrees of preparedness may exacerbate inequality between richer and poorer areas within countries and between regions. All these changes will ripple through other industries – from insurance to repair, trucking to taxi driving. AV technology has an impact that goes beyond the boundaries of a single industry.

Until the auto and tech world can address all these technical, ethical, security and legal issues, the AV future will continue to be a dream.

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Annex

Table 1 – List of CPC codes compiles based on info from UKIPO, EPO, IP Australia.

	CPC codes
CPC only	G05D 1/0088 G05D2201/0207 G05D2201/0212 G08G 1/22 B60L2260/40% B60L2230% B60K31/0008 B60K31/0008 B60K2031/0091 B60K31/0058 B60K31/0066 B60W2550/40 B60W2600% G01S15/88 G06K9/00791 G06T2207/30252 G08G1/096791 G08G1/16 G08G1/22 H04L67/12 Y02P90/285
CPC + Keyword in abstract (autonomous | unmanned | driver[.]{0,}less | agv)	G08G 1/16% B60W 30/% B60W 2030/% B60W 40/% B60W 2040/% B60W 50/% B60W 2050/% B62D Y02T 10 B60Y 2200/11 G01S 7/022 G01S 7/4806
CPC + Keyword in abstract (autonomous | unmanned | driver[.]{0,}less | agv) (ground | car | cars| lorri | lorry | road | street | highway| convoy| platoon | fleet) **Not** (air | aer | drone| flight| flies| fly)	G05D 1/021/% G05D 1/02 G01S 17/936 G01S 17/93 G01S 15/931/% G01S 15/93 Y02T 90/% G01S 13/931 G01S 13/93 B60W% B60L% B60Y% G01S 17/88
CPC + Keyword in title (autonomous | unmanned | driver[.]{0,}**less** | agv)	G08G 1/16 B60W 30/% B60W 40/% B60W 50/% B62D% Y02T 10/% B60Y 2200/11

CPC + Keyword in title (autonomous | unmanned | driver[.]{0,}less | agv) (ground | car | cars| lorri | lorry| road| street| highway | convoy| platoon) **Not** (air| aer | drone | flight | flies| fly)	G05D 1/021 G05D 1/02 G01S 17/936 G01S 17/93 G01S 15/931 G01S 15/93 Y02T 90/% G01S 13/931 G01S 13/93 B60W% B60L% B60Y%
IPC + Keyword in abstract (autonomous | unmanned | driver[.]{0,}less | agv)	G08G 1/16% B60W 30/% B60W 40/% B60W 50/% B62D% Y02T 10/% B60Y 2200/11
IPC + Keyword in abstract (autonomous | unmanned | driver[.]{0,}less | agv) (ground| car | cars| lorri | lorry | road | street | highway | convoy | platoon | fleet) **Not** (air| aer | drone| flight | flies | fly)	G05D 1/021 G05D 1/02 G01S 17/936 G01S 17/93 G01S 15/931 G01S 15/93 Y02T 90/% G01S 13/931 G01S 13/93 B60W% B60L% B60Y%
IPC + Keyword in title (autonomous | unmanned | driver[.]{0,}less | agv)	G08G 1/16 B60W 30/% B60W 40/% B60W 50/% B62D% Y02T 10/% B60Y 2200/11
IPC + Keyword in title (autonomous | unmanned |driver[.]{0,}less | agv) (ground | car | cars | lorri | lorry | road | street | highway | convoy | platoon | fleet) **Not** (air | aer | drone | flight | flies | fly)	G05D 1/021 G05D 1/02 G01S 17/936 G01S 17/93 G01S 15/931 G01S 15/93 Y02T 90/% G01S 13/931 G01S 13/93 B60W% B60L% B60Y%

Table 2 - Secondary keywords included in Q2

Adaptive cruise control
Advanced driver assistance system
automated driving system
automated lane change maneuver
automatic vehicle control
automatic vehicle following
automotive radar
automotive sensors
autonomous mobile robots
autonomous navigation
Autonomous valet parking
autonomous vehicular networks
Autonomous-vehicle lane
collision avoidance
crash avoidance
DARPA
DARPA urban challenge
Defense Advanced Research Projects Agency (DARPA) urban challenge
drivable-region detection
intelligent cruise control vehicles
Intelligent unmanned autonomous system
LADAR
laser imaging detection and ranging
LIDAR
LIDAR object detection
light detection and ranging (LIDAR)
Look-ahead sensing
Moving vehicle detection
obstacle avoidance
obstacle detection
pedestrian detection
pedestrian-crossing detection
platoon
predictive cruise control
Unmanned ground vehicle
Unmanned surface vehicles
Vehicle automation
vehicle detection
vision-based guidance
wheeled robotic vehicle

Table 3 – Eliminated (WoS) subjects

Anatomy; Morphology
Art
Astronomy; Astrophysics
Audiology; Speech-Language Pathology
Behavioral Sciences
Biochemistry; Molecular Biology
Biodiversity; Conservation
Biophysics
Biotechnology; Applied Microbiology
Cardiovascular System; Cardiology
Cell Biology
Chemistry
Crystallography
Developmental Biology
Education; Educational Research
Emergency Medicine
Endocrinology; Metabolism
Entomology
Environmental Sciences; Ecology
Evolutionary Biology
Fisheries
Food Science; Technology
Forestry
Gastroenterology; Hepatology
General; Internal Medicine
Geochemistry; Geophysics
Geography
Geology
Geriatrics; Gerontology
Health Care Sciences; Services
Immunology
Infectious Diseases
Information Science; Library Science
Life Sciences; Biomedicine - Other Topics
Linguistics
Marine; Freshwater Biology
Medical Informatics
Medical Laboratory Technology
Meteorology; Atmospheric Sciences
Microbiology
Mineralogy
Mining; Mineral Processing
Neurosciences; Neurology
Nuclear Science; Technology
Nursing
Nutrition; Dietetics

Obstetrics; Gynecology
Oceanography
Ophthalmology
Orthopedics
Otorhinolaryngology
Pathology
Pediatrics
Pharmacology; Pharmacy
Physiology
Plant Sciences
Psychiatry
Psychology
Public Environmental; Occupational Health
Radiology Nuclear Medicine; Medical Imaging
Rehabilitation
Research; Experimental Medicine
Respiratory System
Rheumatology
Social Sciences - Other Topics
Sport Sciences
Surgery
Toxicology
Transplantation
Tropical Medicine
Urology; Nephrology
Veterinary Sciences
Water Resources
Zoology

Table 4 - 100 AV applicants ordered by number of patents (1995-2017)

Applicant name	Country code	# patents	Rank
FORD	US	357	1
TOYOTA JIDOSHA	JP	320	2
ROBERT BOSCH	DE	264	3
DAIMLER	DE	226	4
HONDA	JP	171	5
PANASONIC (MATSUSHITA)	JP	159	6
GEN MOTORS	US	159	6
NISSAN	JP	153	8
BAYERISCHE MOTOREN WERKE	DE	147	9
GOOGLE	US	131	10
TOYOTA	US	125	11
HITACHI	JP	121	12
HYUNDAI	KR	120	13
IROBOT	US	120	13
*NA	JP	118	15
AUDI	DE	105	16
SIEMENS	DE	104	17
SCANIA CV	SE	100	18
NIPPON STEEL SUMITOMO	JP	92	19
GEN ELEC	US	91	20
DENSO	JP	91	20
INT BUSINESS MACHINES	US	84	22
WAL MART STORES	US	83	23
VOLKSWAGEN	DE	77	24
BOEING	US	73	25
CONTINENTAL AUTOMOTIVE	DE	68	26
MAYER YARON	IL	66	27
*NA	JP	65	28
QUALCOMM	US	63	29
VOLVO CAR	SE	62	30
UBER	US	62	30
DELPHI	US	62	30
*NA	KR	61	33
SAMSUNG ELECTRONICS	KR	60	34
DEERE	US	55	35
FLIR SYST	US	53	36
LOCKHEED	US	52	37
VALEO SCHALTER SENSOREN	DE	52	37
MOBILEYE VISION	IL	51	39
THUNDER POWER NEW ENERGY VEHICLE	HK	51	39
LG ELECTRONICS	KR	51	39
SONY	JP	50	42
RICOH	JP	49	43
TOSHIBA	JP	46	44
STATE FARM MUTUAL AUTOMOBILE INSURANCE	US	45	45
ETRI	KR	44	46
MAGNA ELECTRONICS	US	44	46
BAE SYST	GB	43	48
JAGUAR LAND ROVER	GB	41	49
DONNELLY	US	41	49

Applicant name	Country code	# patents	Rank
FEDEX	US	41	49
SHARP	JP	40	52
CATERPILLAR	US	38	53
PEUGEOT	FR	37	54
HONEYWELL INT	US	36	55
BAIDU	US	36	55
RENAULT	FR	35	57
CONTINENTAL TEVES	DE	35	57
NEXTEV	US	35	57
FUJI HEAVY	JP	35	57
*NA	JP	34	61
CONNAUGHT ELECTRONICS	IE	33	62
LSIS	KR	33	62
*NA	JP	32	64
FUJITSU	JP	32	64
KOMATSU	JP	32	64
AEROVIRONMENT	US	31	67
HYUNDAI MOBIS	KR	31	67
FISHER ROSEMOUNT SYST	US	30	69
FARADAY FUTURE	US	29	70
PROGENITY	US	28	71
GOGORO	CN	28	71
DEEPMAP	US	28	71
MURATA MACHINERY	JP	27	74
MANDO	KR	26	75
BRAIN	US	26	75
AUTOMOTIVE INT	US	25	77
PROTERRA	US	25	77
WAYMO	US	25	77
BRAGI	DE	24	80
MITSUBISHI HEAVY	JP	24	80
AGENCY DEFENSE DEV	KR	22	82
*NA	KR	22	82
NIPPON YUSOKI	JP	22	82
PORSCHE	DE	22	82
STEERING SOLUTIONS	US	22	82
CNH AMERICA	US	21	87
YAMAHA	JP	21	87
AMAZON	US	20	89
APPLE	US	20	89
CROWN EQUIP	US	20	89
CONTI TEMIC MICROELECTRONIC	DE	20	89
BAIDU ONLINE NETWORK BEIJING	CN	20	89
FATDOOR	US	20	89
BEIJING INST TECH	CN	19	95
FARNOW	AU	19	95
INRIX	US	19	95
NIO	US	19	95
INTEL	US	19	95
NUTONOMY	US	19	95

* N/A: Due to encoding problems of PATSTAT, these names are not available
****** Counts of single and patent families

Table 5 - 100 AV applicants ordered by number of patents (1990-2000)

Applicant name	Country code	# patents	Rank
NIPPON STEEL SUMITOMO	JP	48	1
HONDA	JP	48	1
TOYODA AUTOMATIC LOOM WORKS	JP	39	3
KOBE STEEL	JP	37	4
MEIDENSHA	JP	31	5
HITACHI	JP	31	5
AUTOMOTIVE INT	US	24	7
DAIMLER	DE	21	8
MURATA MACHINERY	JP	20	9
FUJITSU	JP	19	10
HUGHES AIRCRAFT	JP	18	11
KOMATSU	JP	17	12
NISSAN	JP	17	12
FARNOW	AU	17	12
NIPPON YUSOKI	JP	16	15
DONNELLY	US	16	15
TOYOTA JIDOSHA	JP	15	17
FUJI HEAVY	JP	14	18
PANASONIC (MATSUSHITA)	JP	13	19
SIEMENS	DE	12	20
YAMAHA	JP	11	21
MITSUBISHI HEAVY	JP	9	22
TOSHIBA	JP	9	22
CATERPILLAR	US	9	22
YAZAKI	JP	9	22
NULL	KR	7	26
YANMAR AGRICULT EQUIP	JP	7	26
MAZDA	JP	7	26
KOMATSU FORKLIFT	JP	6	29
MINOLTA	JP	6	29
SAMSUNG ELECTRONICS	KR	5	31
H R ROSS	US	5	31
KAWASAKI HEAVY	JP	5	31
DELCO ELECTRONICS	US	5	31
FUJI	JP	5	31
YANMAR DIESEL ENGINE	JP	5	31
VOLKSWAGEN	DE	5	31
NISSAN DIESEL	JP	4	38
TOKYU CAR	JP	4	38
GEN ELEC	US	4	38
CATERPILLAR MITSUBISHI	JP	4	38
KUBOTA	JP	4	38
LUZ FUEL ISRAEL	IL	4	38
HYUNDAI	KR	4	38
GENTEX	US	4	38
WEBB	US	4	38
BRIDGESTONE	JP	4	38
HOERICHT ROLF	DE	3	48
THE USA	US	3	48
DAUM PARTNER MASCHINENBA	DE	3	48

Applicant name	Country code	# patents	Rank
AISIN SEIKI	JP	3	48
TOKAI RUBBER	JP	3	48
DENSO	JP	3	48
KAJIMA	JP	3	48
SONY	JP	3	48
DAIFUKU	JP	3	48
HUBBELL	US	3	48
SEIKO EPSON	JP	3	48
TS	JP	3	48
KOCHANNECK UWE	DE	2	60
MORI HIDEO	JP	2	60
UNIV CALIFORNIA	US	2	60
ROSNER STUART	US	2	60
JAPAN TECH RES DEV INST	JP	2	60
INST NAT RES INF AUTOMAT	FR	2	60
KUPERSMIT CARL	US	2	60
TSENG LING YUAN	US	2	60
HARNESS SOGO GIJUTSU KENKYUSHO	JP	2	60
ROBERT BOSCH	DE	2	60
TATSUNO	JP	2	60
SEGA ENTERPRISES	JP	2	60
FUEL	IL	2	60
ZIP CHARGE	JP	2	60
PEUGEOT	FR	2	60
YASKAWA	JP	2	60
CABLECO	FR	2	60
TERBERG BENSCHOP	NL	2	60
TOPY	JP	2	60
INDUMAT	DE	2	60
NIPPON SHARYO SEIZO	JP	2	60
INT BUSINESS MACHINES	US	2	60
IHI	JP	2	60
NORVIK TRACTION	CA	2	60
FORD	US	2	60
BAYERISCHE MOTOREN WERKE	DE	2	60
REVEO	US	2	60
IPR INVESTMENT	GB	2	60
BASF	DE	2	60
BIRLE SIGMUND	DE	1	89
FREDERICH FRITZ	DE	1	89
MCNAUGHT TERRY JOSHUA ROBERT	CA	1	89
WEBB JERVIS B	US	1	89
SHANGHAI INST FIRE FIGHTING	CN	1	89
THOMSON TRT DEFENSE	FR	1	89
ASS	US	1	89
DONGHUA UNIV	CN	1	89
RAILWAY TECH RES INST	JP	1	89
VALEO VISION	FR	1	89
NIPPON HODO	JP	1	89
ABAD JOSE	FR	1	89

Table 6 - 100 AV applicants ordered by number of patents (2010-2017)

Applicant name	Country code	# patents	Rank
FORD	US	347	1
ROBERT BOSCH	DE	227	2
TOYOTA JIDOSHA	JP	206	3
DAIMLER	DE	163	4
GEN MOTORS	US	161	5
BAYERISCHE MOTOREN WERKE	DE	130	6
GOOGLE	US	127	7
NISSAN	JP	126	8
*N/A	JP	118	9
PANASONIC (MATSUSHITA)	JP	115	10
HONDA	JP	113	11
TOYOTA	US	112	12
HYUNDAI	KR	106	13
AUDI	DE	105	14
SCANIA CV	SE	100	15
SIEMENS	DE	92	16
WAL MART STORES	US	83	17
INT BUSINESS MACHINES	US	77	18
HITACHI	JP	76	19
GEN ELEC	US	71	20
CONTINENTAL AUTOMOTIVE	DE	67	21
DENSO	JP	67	21
VOLKSWAGEN	DE	66	23
*N/A	JP	65	24
BOEING	US	63	25
QUALCOMM	US	63	25
UBER	US	62	27
*N/A	KR	61	28
IROBOT	US	60	29
NIPPON STEEL SUMITOMO	JP	58	30
DELPHI	US	58	30
VOLVO CAR	SE	57	32
MOBILEYE VISION	IL	55	33
THUNDER POWER NEW ENERGY VEHICLE	HK	51	34
LG ELECTRONICS	KR	49	35
FLIR SYST	US	49	35
STATE FARM MUTUAL AUTOMOBILE INSURANCE	US	45	37
VALEO SCHALTER SENSOREN	DE	45	37
SAMSUNG ELECTRONICS	KR	43	39
RICOH	JP	43	39
FEDEX	US	41	41
JAGUAR LAND ROVER	GB	41	41
LOCKHEED	US	38	43
MAGNA ELECTRONICS	US	38	43
TOSHIBA	JP	36	45
BAIDU	US	36	45
CATERPILLAR	US	36	45
SHARP	JP	36	45
ETRI	KR	35	49
NEXTEV	US	35	49

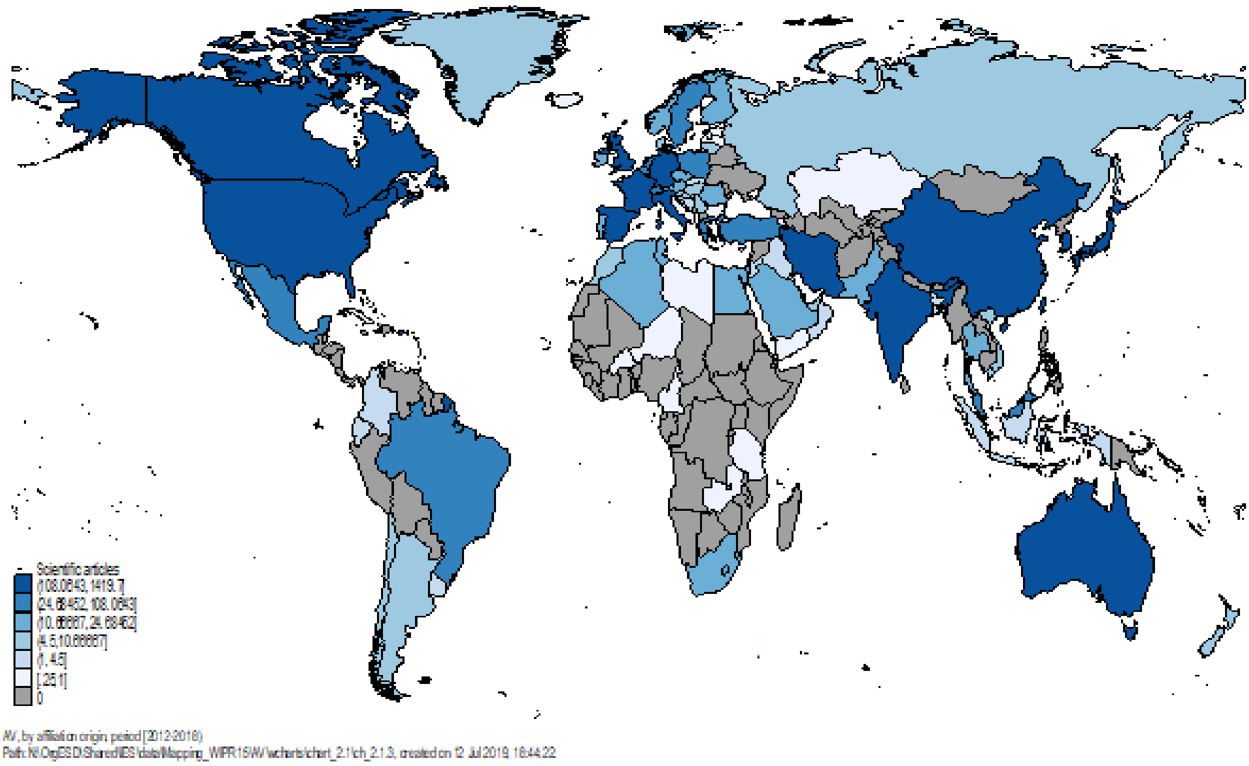
Applicant name	Country code	# patents	Rank
*N/A	JP	34	51
LSIS	KR	33	52
*N/A	JP	32	53
PROGENITY	US	32	53
CONNAUGHT ELECTRONICS	IE	32	53
RENAULT	FR	31	56
PEUGEOT	FR	31	56
HYUNDAI MOBIS	KR	31	56
SONY	JP	29	59
FISHER ROSEMOUNT SYST	US	29	59
FARADAY FUTURE	US	29	59
GOGORO	CN	28	62
DEERE	US	28	62
DEEPMAP	US	28	62
BAE SYST	GB	27	65
CONTINENTAL TEVES	DE	27	65
BRAIN	US	26	67
AEROVIRONMENT	US	26	67
WAYMO	US	25	69
BRAGI	DE	24	70
MANDO	KR	24	70
STEERING SOLUTIONS	US	22	72
PORSCHE	DE	22	72
AGENCY DEFENSE DEV	KR	21	74
*N/A	KR	21	74
PROTERRA	US	21	74
CROWN EQUIP	US	20	77
AMAZON	US	20	77
BAIDU ONLINE NETWORK BEIJING	CN	20	77
BEIJING INST TECH	CN	19	80
INRIX	US	19	80
NUTONOMY	US	19	80
INTEL	US	19	80
NIO	US	19	80
CNH AMERICA	US	19	80
APPLE	US	19	80
CONTI TEMIC MICROELECTRONIC	DE	19	80
ZONAR SYST	US	18	88
HERE GLOBAL	NL	18	88
SHENZHEN CM INNOTECH	CN	17	90
WALMART APOLLO	US	17	90
HONEYWELL INT	US	17	90
*N/A	CN	16	93
AFFECTIVA	US	16	93
SCHNEIDER	US	16	93
KUBOTA	JP	16	93
MITSUBISHI NICHIYU FORKLIFT	JP	16	93
FUJI HEAVY	JP	15	98
ACTIVE KNOWLEDGE	IL	15	98
LEAR	US	15	98

* N/A: Due to encoding problems of PATSTAT, these names are not available
****** Counts of single and patent families

Map 1

Developing countries are active in production of scientific publication in AV technology in the recent years

Geographical distribution of AV-related scientific publication around the world (2012-2018)



[i] See Teece (2018)
[ii] See Tripsas (1997)
[iii] See Zucker and Darby (1997)
[iv] See Rothaermel (2001)
[v] See Higgins and Rodriguez (2006)
[vi] See Rothaermel and Hess (2007)
[vii] See Klepper (1997), Audrestsch and Feldman (1996), Abernathy and Utterback (1978), Jovanovic and MacDonald (1994).
[viii] See Abernathy and Clark (1985) and Klepper (1997).
[ix] See Klepper (1997).
[x] See Global EV Outlook (2019).
[xi] See Prahalad and Hamel (1997).
[xii] See Intel (n.d.).
[xiii] Tech includes: electronics, ICTs, semiconductors and audio-visuals. Auto includes: instruments, material, machines, engines and transport, civil engineering. Others include: biopharma, chemicals and environment and consumer goods.
[xiv] See Hummel (2019).
[xv] See Reuters (2019).
[xvi] A technology stack is the list of all the tools and technologies used to build and run a single product.
[xvii] See VIA Technologies (2018).
[xviii] See Randall (2019).
[xix] See Hawkins (2019).
[xx] See Chesbrough (2003)
[xxi] See Arora and Gambardella (1990).
[xxii] See Teece (1986).
[xxiii] See Gans and Stern (2003) and Cozzolino and Rothaermel (2018).
[xxiv] See Perkins and Murmann (2018).
[xxv] See MacDuffie (2018), Jiang and Lu (2018), Teece (2018).
[xxvi] See Capron and Mitchell (2012).
[xxvii] The majority of the data was collected from the latest media and company announcements. However, at times this info may be misleading as other motivations like market signaling and gaining venture capitalist attention might be behind the announcements.
[xxviii] See Bresnahan and Tratjenberg (1995).
[xxix] The patent and scientific publication data used in this section are a sub-sample of those explained in technical notes and Chapter 2 WIPR 2019. For more information about detailed search strategy and data collection please check the respective working papers.
[xxx] According to SAE (J3016) there are 0 to 5 Automation Levels, 0 being no automation to 5 being full automation.
[xxxi] See Lee and Lim (2001).
[xxxii] See Saxenian (1996) and (2007).
[xxxiii] See Ghemawat (1991).