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## Breakthrough technologies – Robotics, innovation and intellectual property

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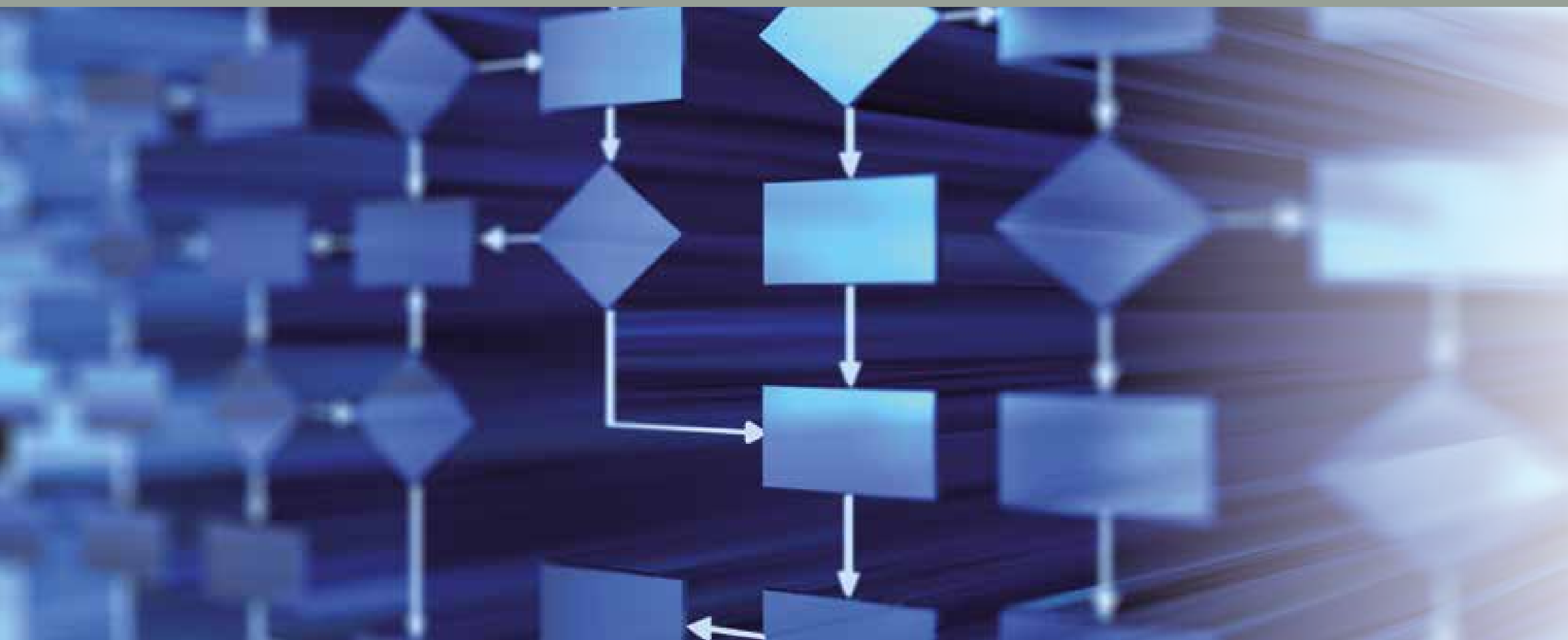

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# Breakthrough Technologies – Robotics, Innovation and Intellectual Property

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**Abstract**

Robotics technology and the increasing sophistication of artificial intelligence are breakthrough innovations with significant growth prospects and the potential to disrupt existing economic and social facets of everyday life. Few studies have analyzed the developments of robotics innovation. This paper closes this gap by analyzing how innovation in robotics is taking place, how it diffuses, and what role intellectual property (IP) plays. The paper finds that robotics clusters are mainly located in the US, Europe, but increasingly also in the Republic of Korea and China. The robotics innovation ecosystem builds on cooperative networks of actors, including individuals, research institutions, and firms. Governments play a significant role in supporting robotics innovation, in particular through funding, military demand, and national robotics strategies. Robotics competitions and prizes provide for an important incentive to innovation. Patents are used to exclude third parties, to secure freedom to operate, to license technologies and to avoid litigation. The countries with the highest number of filings are Japan, China, Republic of Korea and the US. The growing stock of patents owned by universities and PROs, in particular in China, is noteworthy too. Automotive and electronics companies are still the largest patent filers, but new actors in fields such as medical technologies and the Internet are emerging. Secrecy is often used as a tool to appropriate innovation. Copyright protection is relevant to robotics too, mainly in its role in protecting software, and more recently in protecting so-called *Netlists*. Finally, proprietary approaches co-exist with open-source robotics platforms which are developing rapidly in robotics clusters.

**Keywords:** robotics, robot, artificial intelligence, innovation, patent, trade secret, copyright

**JEL Classification:** F23, L86, O3, L6

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*At bottom, robotics is about us. It is the discipline of emulating our lives, of wondering how we work.*

Rod Grupen
Director of the Laboratory for Perceptual Robotics
University of Massachusetts Amherst

## Introduction

The looming sophistication of robots and artificial intelligence (AI) and its consequences are currently the subject of numerous debates. The fact that humanoid robots have recently been trialed in supermarkets, schools, hospitals and retirement homes in the Europe, the United States and Japan has given the field of robotics new prominence.

Technologists, economists, lawyers and other disciplines are speculating about the potential uses, the social and the economic impacts of robotics innovation. In economic circles, the debate often focusses on the - the potential positive or negative - employment impacts of robots. Social scientists are debating the social influence of artificial companions. Hollywood movies such as Ex_Machina or Her, too, have put the spotlight on the potential upcoming superiority of AI which might increasingly rival human intelligence. All observers agree that the pervasive uptake and impacts of robotics innovation is imminent, and potentially far-reaching.

Yet, despite the central attention devoted to this expanding field of technology, few studies have analyzed the developments of robotics innovation, and the underlying innovation eco-system. Moreover, while the role of intellectual property (IP) is analyzed with respect to numerous high-technology fields, such as information-, nano-, or bio-technology, literally no studies are devoted to the use and uptake of various forms of IP for robotics innovation. The few articles devoted to robotics innovation in prominent innovation journals date back to the 1990s.[1]

This paper aims to fill this gap by providing an up-to-date analysis of the robotics innovation system, and the corresponding role of IP. Section 1 describes the history of robotics innovation. Section 2 assesses its underlying economic contribution. Section 3 describes the robotics innovation ecosystem. Section 4 analyzes the uptake and relevance of different strands of IP to robotics innovation. Original patent landscapes for robotics are presented, which also highlight the past and current epicenters of robotics innovation. A technical annex sets out the computational approach taken to elaborate these patent statistics and rankings.

This is part of a broader series of studies for WIPO's *World IP Report 2015* as in WIPO (2015) exploring the concrete linkages between innovation, IP, and growth in six areas of breakthrough innovation (airplanes, antibiotics, semiconductors, 3D printing, nano-technology and robotics).

[1] See for example in *Research Policy*, see Kumaresan and Miyazaki (1999).

## 1. The Development of Robotics and their Economic Importance

Robotics is the field of technology which drives the development of robots for application in areas as diverse as car factories, construction sites, schools, hospitals and private homes. Industrial robot arms have been in use for industrial automation in automotive and other manufacturing businesses for more than three or four decades. But various strands of existing and newer research fields, such as AI and sensing, have been combined in more recent years to produce autonomous "advanced" robots with more widespread potential use across the economy and society.

### 1.1 What is a robot? Evolving definitions

In part driven by aforementioned Hollywood movies, most laypersons perceive "robots" to be primarily, or exclusively, humanoid robots. However, humanoid robots are only a small subset of the robotics industry.

Encyclopedia Britannica defines a robot as "any automatically operated machine that replaces human effort." According to the International Federation of Robotics (IFR), "[a] robot is an actuated mechanism programmable in two or more axes with a degree of autonomy, moving within its environment, to perform intended tasks".[2] In turn, the majority of practitioners and scholars consider a robot to be any "machine capable of sensing its environment and reacting to that environment based on an independent decision-making capability".[3]

The term autonomy is often used to underline the difference between robots and other machines; a robot has the ability to interpret its environment and adjust its actions to achieve a goal. In terms of technological trajectory, robots are evolving from programmed automation, over semi-autonomous to more autonomous complex systems. Fully-autonomous systems are able to operate and make "decisions" to complete tasks without human interaction (see Box 1 for a fuller definition).

Box 1 – Robotics evolution and definitions

**Remote Controlled**

A remote control device is a device that can be controlled from a remote location. Based on the most common definition of a "robot", remote controlled devices would not be considered a "robot". Nevertheless, the robotics industry has accepted certain purely remote controlled devices as within the industry of robotics. For example, telepresence devices are often referred to as robots, or even robotic-telepresence devices, despite the fact that some telepresence devices are purely remote controlled. The same is true for certain toys, as well as for certain educational devices. Examples of remote controlled devices frequently considered to be within the bounds of the robotics industry include telepresence robots, remotely controlled humanoid robots, robotic assisted surgical devices, exoskeletons, and Unmanned Aerial Vehicles (UAV), also known as Unmanned Aerial Systems (UAS) or "drones."

[2] See IFR.

[3] See Springer (2013), p. 1-5.

**Semi-Autonomous**
Semi-autonomous devices still interact with and are controlled by human operators, but are not purely remote controlled devices as semi-autonomous systems provide guidance to their human operators to ease and/or assist in the device's operation. Robots whose operation is managed by a human operator is generally considered semi-autonomous. Examples include semi-autonomous features frequently becoming more common in cars, as well as certain industrial robots that require an operator to provide detailed commands.

**Fully Autonomous**
Fully-autonomous devices are those devices that are able to operate, including the ability to make "decisions" within the environment for which it was designed and in order to further the task it was designed to accomplish, without human interaction. Fully-autonomous devices are not typically designed to think creatively, but there is some admittedly blurred lines as certain fully-autonomous devices are necessarily designed to operate in unpredictable environments for which the fully-autonomous devices' decisions are not predetermined.

**Artificial Intelligence**
AI is generally defined as its own area of computer science that is focused on computer-based devices being capable of making intelligent human-like decisions. Although admittedly a blurry line, one divide between fully-autonomous and AI is the difference between a device making basic unsophisticated decisions (autonomy) and a device that makes creative decisions. AI is considered by some practitioners to be within the robotics industry, but many other practitioners consider artificial intelligence to be its own field of technology; albeit with potentially profound implications on the robotics industry. The later view is based on the understanding that artificial intelligence is grounded in computer-science without necessarily any hardware application. Although artificial intelligence incorporated into a movable hardware device is anticipated as a potential reality within the robotics industry, artificial intelligence can be entirely separate from any hardware device.

## 1.2 History of Robotics

### From industrial arms for automation

Robots, in their most basic form, are not new. The history of robotics started in ancient Greek with *automatons,* essentially non-electronic moving machines which displayed moving objects. The invention of simple automatons continually evolved henceforth, but robots in their current form took off with the process of industrialization, to perform repetitive tasks.

In the more recent history of industrial robots, a few key inventions in two areas stand out as having led to the first incarnation of robots for industrial automation.[4] First, *control systems* allowing humans or computers to control and steer robots from a distance, and second, *mechanical manipulation systems* such as robotic arms or legs to move or grab objects.

[4] See IFR (2012).

As for mechanical manipulation systems, the first industrial robot was developed in 1937 in the form of a small crane. The development of robotic legs and arms was furthered by W.G. Walter, who built the first autonomous robot in the late 1940s.[5] The breakthrough enabling the development of the robotics industry, however, was when George Devol invented and patented the first automatically operated programmable robotic arm in the mid-1950s.[6] Devol then partnered with Joseph Engelberger, considered by many scholars to be the "Father of Robotics",[7] to create a company called Unimation, which produced a robot in 1956 based on Devol's patents. This started the commercialization of industrial robots.[8]

Robotic arms have since been fine-tuned and improved. The first computer-controlled revolute electric arm, for instance, was developed at the Case Institute of Technology, Case Western Reserve University, US. In 1969, researchers at Stanford University invented the so-called Programmable Universal Manipulation Arm, allowing for more sophisticated control for assembly and automation.[9] One of these researchers, Victor Scheinman, started Vicarm Inc. to manufacture the arm, which proved fundamental to the development of the robotics industry; he ultimately sold the company to Unimation in 1977.

Largely based on the work of the aforementioned inventors and firms, the first commercial robots were deployed on General Motors' assembly lines in the USA in 1961.[10] The first industrial robot in Europe, a Unimate, was installed in Sweden in 1967. In 1969, the company Trallfa of Norway offered the first commercial painting robot. In 1973, ABB Robotics and KUKA Robotics brought their first robots to market. Since then, the functionality and control of robotic mechanical parts have been continually improved by the robotics industry.

Approximately a decade after Devol filed his patent, Japanese companies began to develop and produce their own robots pursuant to a license agreement with Unimation. By 1970, robotic manufacturing had proliferated throughout the automotive industry in the US and Japan. By the late 1980s, Japan – led by the robotics divisions of Fanuc, Matsushita Electric Industrial Company, Mitsubishi Group and Honda Motor Company – was the world leader in the manufacture and use of industrial robots.

Parallel key inventions in the area of packaging robots – for instance, the Delta packaging robot developed at the Federal Institute of Technology of Lausanne, yielding 28 patents – modernized the packaging industry.

A full-scale humanoid robot developed at Waseda University in Japan laid the foundation for follow-on innovation in the field, facilitating enhanced human–robot interaction relevant to today's consumer-oriented robot markets. While many historians have discussed evidence of early pre-computer based use of "legs" for movement, the earliest breakthroughs concerning machines that could walk via two or more legs occurred in the 1960s and 1970s.

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[5] US Patent 2,679,940. Willard L.V. Pollard and Harold A. Roselund, working for DeVilbiss Co., filed a patent for the first programmable mechanized paint-sprayer in 1942.

[6] US Patent 2,988,237. See also Nof (1999).

[7] It should be noted, however, that many scholars and practitioners, especially those that consider remote controlled devices to be part of the robotics field, also consider Nikola Tesla to be the "Father of Robotics" based, at least in part, on his 1898 invention and patent of a remote controlled boat (see United States Patent No. 613,809).

[8] See Rosheim (1994).

[9] Scheinman (2015).

[10] IFR (2012).

Yet, such technology is not yet prevalent within commercialized products despite the decades of research that have occurred since the early breakthroughs in this area.

**…toward autonomous systems built on artificial intelligence and connectivity**

In the journey toward more capable robots, researchers have since worked on increasing autonomy and improving interaction between humans and robots. New materials and innovations in various fields outside the robotics area such as artificial intelligence (AI), mechatronics, navigation, sensing, object recognition and information processing are the core technological developments furthering robotics today.[11] The research has become more interdisciplinary.

In particular, innovation in software and AI will be key technologies for next-generation robots. This matters to help robots maneuver and circumvent obstacles. The seminal breakthrough in developing algorithms instrumental for robotic path planning took place in the mid-1980s and is credited to Randall Smith and Peter Cheeseman.[12] The result of such seminal research on the problem of Simultaneous Localization and Mapping (SLAM) led to the development of SLAM algorithms, which many robotics companies still use as of the date of this report, albeit with modifications tailored to the environment and purpose of their specific robot. Algorithms are increasingly central to how robots make more complex decisions, for instance, how home or service robots simulate emotions. Researchers are currently working on software that will mimic the human brain, honing language and decision-making skills.

Based on improved connectivity, sensors and processing power, robots are becoming increasingly data-driven, and linked over more intelligent networks. As such, innovation is increasingly about software and hardware integration and thus the delivery of so-called integrated robotic and intelligent operational systems. On the application level, the development of autonomous vehicles and drones is seen as an extension of robotics.

[11] Kumaresan and Miyazaki (1999).

[12] Smith and Cheeseman (1986).

## 2. The Economic Contribution of Robotics

Robots already have a demonstrable and significant impact on how manufacturing takes place. Since the start of industrial automation in the 1970s, the uptake of robots in manufacturing has increased significantly. The industrial robot market was estimated to be worth USD 29 billion in 2014, including the cost of software, peripherals and systems engineering (see table 1).

**Table 1: Different estimates of the robotics industry revenues**

| Estimate | Definition | Source |
|---|---|---|
| USD 29 billion (2014)<br>USD 33 billion (2017) | Global market for industrial robotics | IFR (2014a) |
| EUR 50-62 billion (2020) | Global market for industrial robotics | euRobotics (2014) |
| USD 3.6 billion | Global market for service robots (of which USD 1.7 billion for domestic use) | IFR (2014b) |

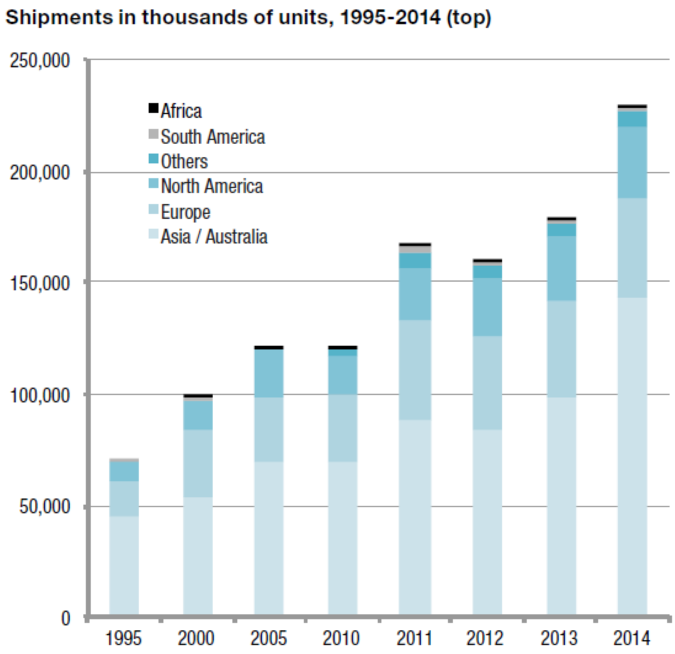
As illustrated by figure 1 (top), the number of robots sold is increasing, reaching about 230,000 units sold in 2014, up from about 70,000 in 1995, and projected to increase rapidly in the next few years. Japan, US and Europe were the initial leaders in terms of market size.

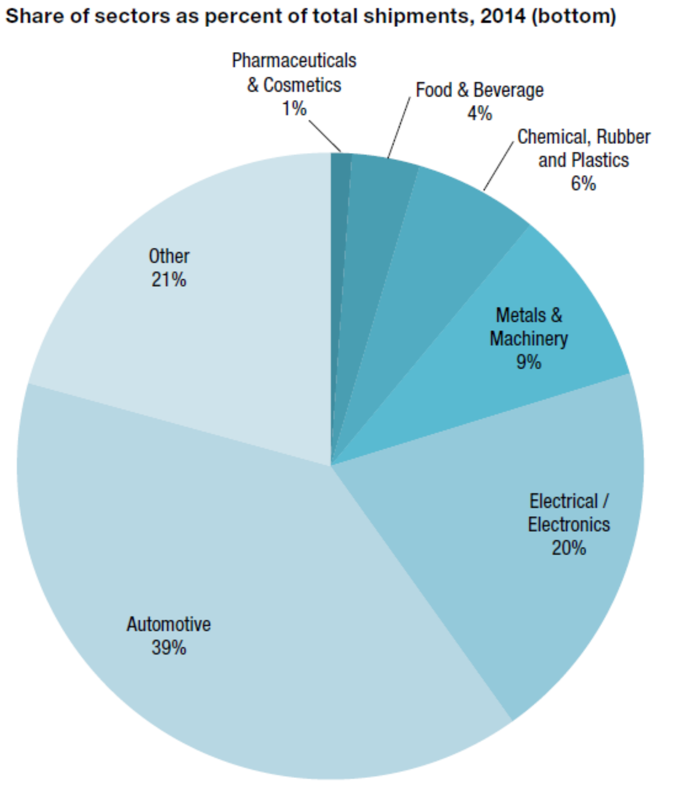
Interestingly, the respective shares of various world regions in global robotics sales has changed little, with Asia leading followed by Europe and North America, and rather small volumes in South America and Africa. Yet within Asia, China has gone from no robots in 1995 to overtaking Japan to become the largest robot market. The Republic of Korea is now the second biggest user of industrial robots in Asia.[13]

In terms of sectors, the automotive industry continues to be the main driver of automation, followed by the electronics industries (see figure 1, bottom). Innovation will enable more flexible and small-scale manufacturing.

[13] In terms of robotic density, as at 2014 the Republic of Korea had the highest robot density in the world, with 437 units per 10,000 persons employed in the manufacturing industry, followed by Japan (323) and Germany (282). In comparison, China's density was 30, Brazil's 9 and India's 2 (IFR, 2014a).

**Figure 1: Worldwide shipments of industrial robots on the increase, led by Asia and the automotive sector**




Source: Authors based on IFR World Robotics Database, 2014.
Note: The regions as shown here follow the definition of the IFR.

A novel robotics field is the production and use of service robots in areas outside of manufacturing. This category includes robots intended for "professional use" in agriculture, mining, transport – including the large field of unmanned aerial and land vehicles, space and sea exploration, unmanned surveillance, health, education and other fields.[14]

The total number of professional service robots reached USD 3.6 billion in 2014, projected to lead the growth of upcoming robotic use.[15] The largest markets are Japan, the Republic of Korea, the US and Europe. The sectors leading their use are defense, logistics and health. Surgical robot device markets, at USD 3.2 billion in 2014, are anticipated to reach USD 20 billion by 2021.[16]

In addition, robotics in personal and domestic applications, another novel robotics field, has experienced strong global growth with relatively few mass-market products, for example floor-cleaning robots, mowers, robots for education and assistive robots for the elderly.[17] With small to non-existent sales volumes even in 2012 and 2013, the sale of these robot types took off exponentially in 2014 and onwards.

A few consultancy reports have emphasized the wide range of savings generated through advanced robotics in healthcare, manufacturing and services, producing high estimates of the benefits to economic growth.[18] But quantifying the productivity-enhancing contribution of robots in definite terms is challenging.

Robots can increase labor productivity, reduce production cost and improve product quality. In the service sector in particular, robots can also enable entirely new business models. Service robots provide assistance to disabled people, mow lawns, but are also increasingly deployed in service industries such as restaurants or hospitals.

In terms of welfare, robots help humans to avoid strenuous or dangerous work. They also have the potential to contribute solutions to social challenges such as caring for the aging population or achieving environmentally friendly transportation.

In part, the economic gains of robots are directly linked to substituting – and thus automating – part of the currently employed workforce.[19]

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[14] See IFR (2014b).

[15] IFR (2014b).

[16] Wintergreen Research Inc. (2015).

[17] IFR (2014b).

[18] The McKinsey Global Institute estimates that the application of advanced robotics could generate a potential economic boost of USD 1.7 trillion to USD 4.5 trillion a year by 2025, including more than up to USD 2.6 trillion in value from healthcare uses (McKinsey Global Institute, 2013).

[19] Metra Martech (2011), Miller and Atkinson (2013), Frey and Osborne (2013) and Brynjolfsson and McAfee (2014).

On the one hand, more productive labor helps keep manufacturing firms competitive, avoiding their relocation abroad and creating higher-wage jobs. The robotics industry has been particularly focused over the past several years on alleviating fears that the increase in robotics will lead to a decrease in available jobs. Indeed, the robotics industry has conducted research and found evidence to support projections that increased employment opportunities will follow from innovations and development in the robotics industry.[20] Many predict that the advancement and proliferation of robotics may lead to an increase in jobs within certain high income nations as a result of manufacturing re-shoring (also called manufacturing in-shoring) because manufacturing previously outsourced to nations with cheaper labor will be performed in high income nations due to robotics reducing the cost of manufacturing.[21] For example, at a robotics-focused Xconomy conference in April 2013, a well-known roboticist explained that, contrary to the past three decades, during which companies moved their manufacturing to various low income nations based on their low labor costs, such manufacturing will be re-shored to the United States and other high income nations. Such predictions are premised on the decrease in manufacturing costs that will result from industrial and other manufacturing related robotics.[22] If such predictions are accurate, it may be true that the proliferation of robotics will increase jobs and economic growth in high income countries. However, at least in the manufacturing sector, the creation of jobs in high income countries may be at the expense of jobs in middle and low income countries if their primary attraction for their manufacturing industry is low labor costs.[23]

On the other hand, the use of robots is certain to eliminate both low-skilled but also some types of higher-skilled jobs hitherto unaffected by automation. Yet, there are still multiple sources that predict robotics, as a whole, will lead to a decrease in available jobs. Many of these later reports focus only on the loss of current jobs[24] and do not account for the creation of new job types that may not exist today

On balance, the employment effect of robotics is currently uncertain.

In terms of overall economic benefits, another question is whether robotic innovation has diffused to low- and middle-income countries already with meaningful impacts. The installed base of robots outside a few high-income economies and a few exceptions such as China is still limited, including in countries such as Brazil or India, but in particular also in less developed economies. It is expected, though, that firms involved in manufacturing and assembly activities for global or local supply chains will need to upgrade their use of robots, including some in middle-income or even low-income economies that have so far competed on cheap labor alone. Robots are also gaining ground in low-income countries to address quality issues in local manufacturing.

[20] Metra Martech (2011).

[21] See Green, T., Robots, Re-Shoring and America's Manufacturing Renaissance. *Robotics Business Review*, June 10, 2012. See also Christensen et al. (2013), pp. 3 and 10: "The sale of robotics for manufacturing grew 44% during 2011, which is a clear indicator of the revitalization of the production system in the U.S. Robots have been used as a facilitator to inshore manufacturing for companies such as Apple, Lenovo, Foxconn.".

[22] See Christensen et al (2013), p. 10 noting that the increased capabilities of manufacturing robotics and the rising cost of labor in nations traditionally known for cheap manufacturing are both acting as incentives for companies to inshoring manufacturing.

[23] But see RBR Staff, *China 2013: Factory Automation Driving Robot Growth*, Robotics Business Review, December 28, 2012 discussing Blue Paper by Morgan Stanley noting the low demand for robotics in China as of 2013 and predicting that China's demand for robotics would increase due to China's manufacturing industry's need to stay competitive.

[24] See, as an example, Frey and Osborne (2013).

Although the location of companies developing robots and robotics products appears to be occurring in specific high income nations, the impact of certain robotics technologies may have an impact on middle and low income countries akin to that of the internet. In the same way that the internet has allowed certain jobs to be performed remotely, whether from a location in the same region or a different continent, robotics technologies such as telepresence robots or remotely controlled robots with arms will continue to increase the type of jobs that can be performed from a remote location.[25] As the internet and robotics technology continue to evolve, making the location of an employee less important to companies than the ability to perform certain tasks, any nation with sufficiently fast and reliable internet service will be enabling its citizens to compete for jobs. In particular, middle and low income countries may be able to compete for positions in higher income countries for jobs requiring a higher level of intellect or creativity. This phenomenon already exists as a result of the internet, with certain companies thriving on the offering of hiring individuals not necessarily in a close geographic location.[26] Such tasks are primarily restricted to purely internet based deliverables, but with the advancement of certain robotics technologies, could involve physical jobs as well. Although middle and low income nations may not benefit from such advancements if they have slow, unreliable, or heavily restricted internet, certain technologies are currently being developed to resolve such limitations.[27]

## 3. The Robotics Innovation System

As it evolves from the era of industrial automation to the use of advanced robotics across the economy, the present-day robotics innovation system can be characterized by a few key traits.

### 3.1 Concentration in key countries and narrow robotics clusters with strong linkages

Robotics innovation mainly takes place within a few countries and clusters.[28] These clusters thrive on the interface between public and private research, with firms commercializing the resulting innovation.

[25] See Christiansen, et al. (2013), p. 66: "As the Internet continues to evolve, it will inspire a natural progression from sensing at a distance to taking action at a distance. This extension of the Internet into the physical world will serve to further blur the boundaries among community, communication, computing, and services and inspire new dimensions in telecommuting and telepresence applications. Hybrid solutions are likely to emerge that enable distributed human cognition and enable the efficient use of human intelligence. Such solutions will combine the robotics-enabled capability to remotely and autonomously perceive situations requiring intervention with the Internet-enabled capability for human operators to take action from a distance on an as-needed only basis.".

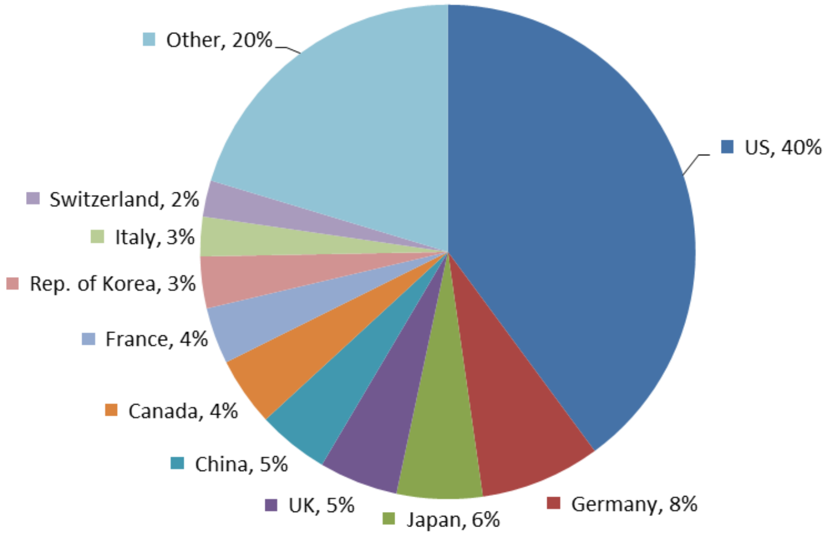
[26] See*, e.g.*, Sarah Halzack, *Elance-oDesk flings open the doors to a massive digital workforce*, The Washington Post, June 13, 2014.

[27] See Juliette Garside, *Facebook Buys UK Maker of Solar-Powered Drones to Expand Internet,* The Guardian, March 28, 2014; See *also* Eliana Dockterman, *Facebook Eyes Using Drones to Deliver Internet,* Time Magazine, March 27, 2014; Gregory S. McNeal, *Google Wants Internet Broadcasting Drones, Plans To Run Tests In New Mexico,* Forbes, September 19, 2014.

[28] Green, T., Rising Power and Influence of Robotics Clusters. *Robotics Business Review*, February 22, 2013.

An analysis of robotics company databases shows that robotics clusters are mainly located in the US, Europe – in particular Germany, France and to some extent the UK – and Japan, but increasingly also in the Republic of Korea and China (see Figure 2).[29] Applicants from the same origins account for the vast majority of patent applications in the field of robotics (see Figure 3). Relative to GDP or population size, Canada, Denmark, Finland, Italy, Israel, the Netherlands, Norway, the Russian Federation, Spain, the UK, Sweden and Switzerland stand out as economies with a big presence of innovative robotics firms.

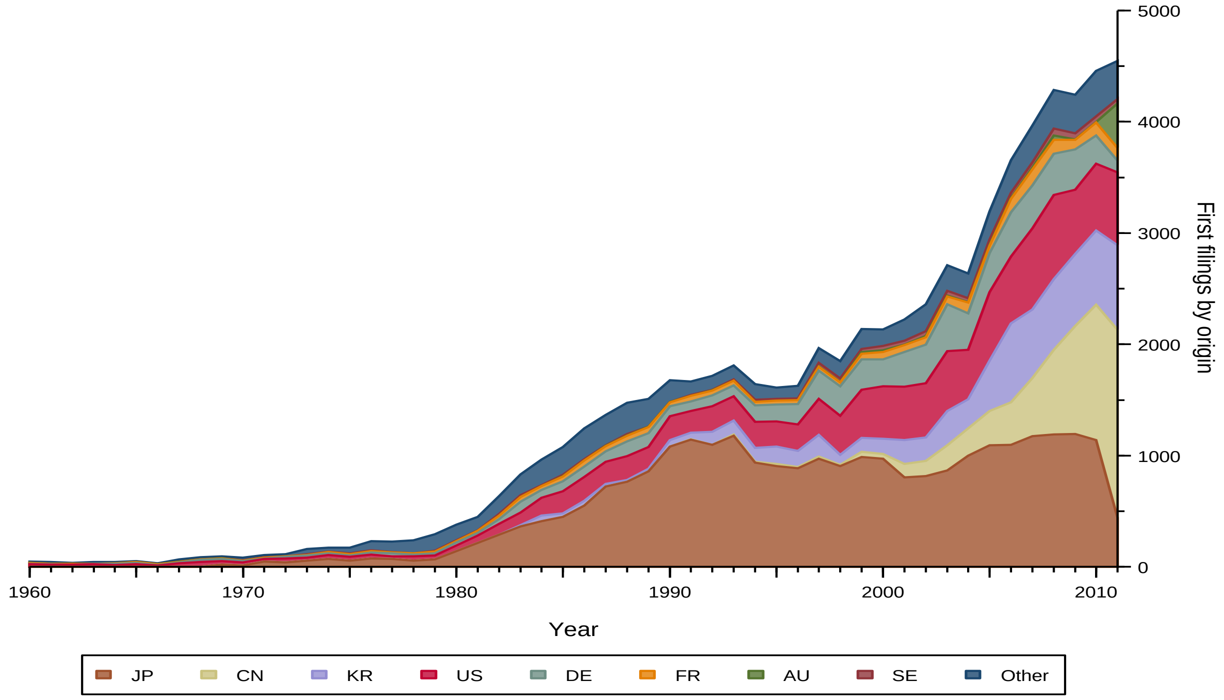
**Figure 2: Main geographic location of robotics companies, 2015**




Source: Authors based on available information from robotics-focused associations and groups, including The Robot Report's Global Map as in Tobe (2015), as well as from the publicly available listing of companies from the Robotics Industry Association (RIA).

[29] Although there is no standard global database for all robotics companies, there have been some attempts to compile such lists, see Tobe (2013).

**Figure 3: Geographic distribution of robotics innovation, 1960-2011**




Notes: Only first filings with at least one patent granted within the patent family
Source: WIPO based on the PATSTAT database (see technical annex).

This picture of inventive activity concentrated in a few nations, also now broadening to include Asian innovative nations, is also mirrored by patent data. Patent data presented in Section 4 attests the importance of US and European and later Japanese inventors at the outset, the emergence of the Republic of Korea in the early 2000s and more recently China.[30]

Within these few countries, robotics clusters are concentrated around specific cities or regions – and often around top universities in the field. For example, in the US, Boston, Silicon Valley and Pittsburgh are generally regarded as the three main robotics clusters. In Europe, the Île-de France region in France (particularly for civil drones), Munich in Germany, Odense in Denmark, Zurich in Switzerland and Robotdalen in Sweden are prominent, among others. In Asia, Bucheon in Korea, Osaka and Nagoya in Japan and Shanghai and Liaoning Province in China are key robotics clusters.

Some companies that excel in robotics innovation are located outside these clusters. They are usually established large companies in the automotive sector, or increasingly also Internet companies, that are well-established in their own field. They have the financial means and the skills to hire robotics experts and to use knowledge developed elsewhere, also often by acquiring newer firms.

Indeed, in terms of robotics innovation and company startups, the majority of activity is in high-income countries, except for China again. China has seen a strong surge of robotics patents and hosts some of the fastest-growing robotics companies such as DJI (Drone Company), and new industrial robot manufacturers such as Siasun and Estun which are driving down the cost of robots.

[30] See also UKIPO (2014).

### 3.2 Highly dynamic and research-intensive collaborative robotics innovation ecosystem

The robotics innovation ecosystem comprises a tight and cooperative network of actors, including individuals, research institutions and universities, and large and small technology-intensive firms. Robotics brings together diverse science and technology breakthroughs to create new applications; while long established, it continues to deliver new inventions as new materials, motive power, control systems, sensing and cyber systems kick in.

As evidenced in section 1.2, individual entrepreneurs and their startups played a critical role in kick-starting and further developing the robotics industry.

Select public research institutions are also crucial actors in the robotics innovation ecosystem. Examples of leading universities include McGill in Canada, Carnegie Mellon in the US, ETH in Switzerland, Imperial College in the UK, Sydney University in Australia, Osaka University in Japan, and the Shanghai Jiao Tong University in China. PROs such as the Korean Institute of Science and Technology, Fraunhofer in Germany, the Industrial Technology Research Institute in Taiwan (Province of China) and the Russian Academy of Sciences are notable too.

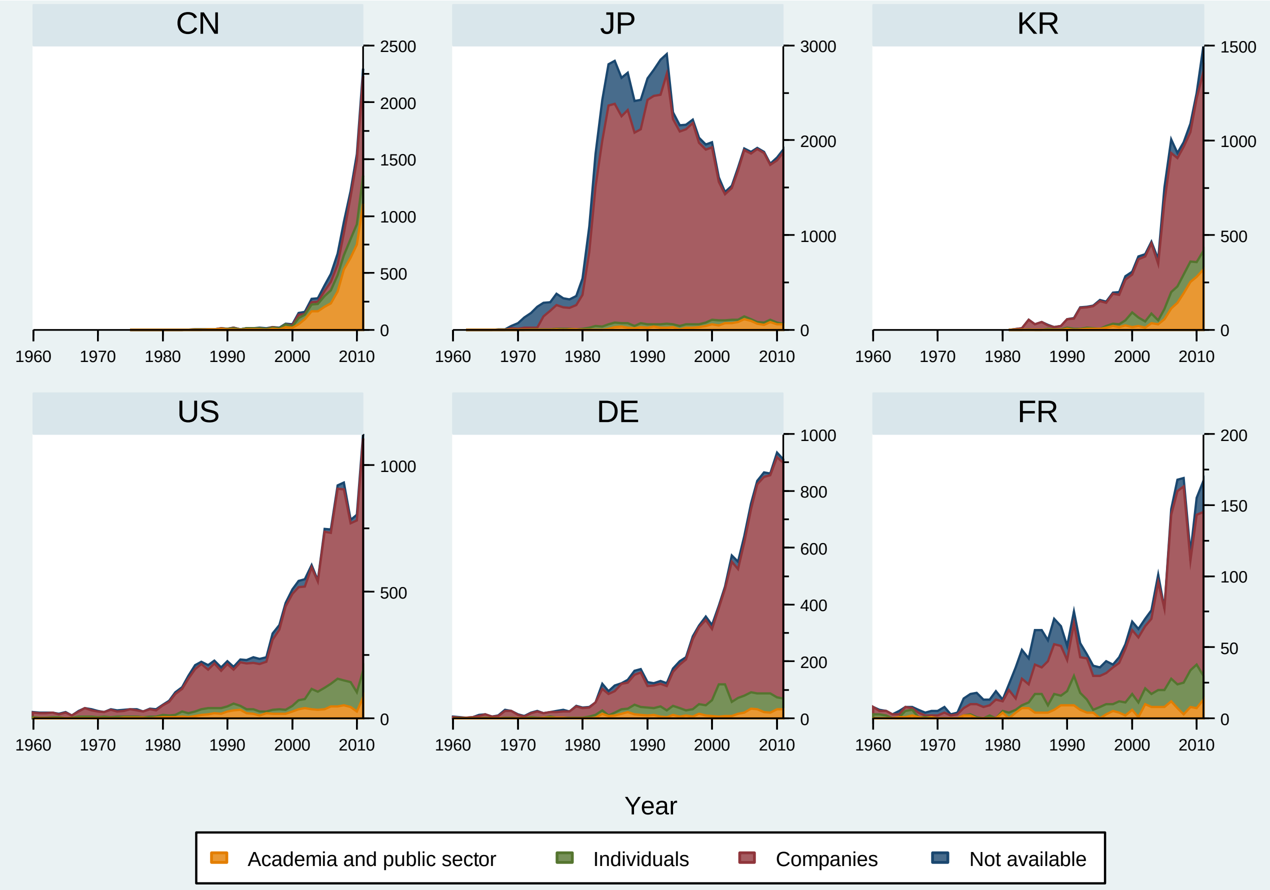
Traditionally, these science institutions play an important role in innovation generally by conducting long-term research whose commercial applications will only be realized far in the future.[31] As depicted in figure 4, the role of academic and public institutions – as well as those of individual entrepreneurs – varies through time and across countries.

In addition, however, in robotics specifically they had and continue to have a major role in furthering development by creating spin-outs and spin-offs, by patenting (see section 4), and through close collaboration with firms.[32] Examples of spin-offs include Empire Robotics, a spin-off of Cornell University, and Schaft Inc., a spin-off of the University of Tokyo. Collaboration between firms and PROs is tight too, with, for instance, KUKA developing lightweight robots with the German Institute of Robotics and Mechatronics. Furthermore, their increased offering of formal robotics degrees has been critical in the development and diffusion of skills, as corporations hire recent graduates.

[31] See Nof (1999), p. 33 stating that the development of electric robots began in university labs.

[32] Nof (1999).

**Figure 4: First patent filings in the field of Robotics by origin and type of applicant, 1960-2011**




Source: WIPO based on the PATSTAT database (see technical annex).

There are also examples of universities collaborating with the private sector beyond simply accepting monetary support for robotics research, including, for example, universities entering into joint development agreements with private companies for the purpose of building robotic technology to solve problems relevant to the private company.[33]

[33] See RBR Staff, *Mining Giant Anglo-American Inks Deal with Carnegie Mellon*, Robotics Business Review, January 9, 2013 discussing Carnegie Mellon University's five-year joint development agreement with Anglo American Plc, pursuant to which CMU's Robotics Institute will design, build and deploy mining robots, robotics tools and autonomous technologies in partnership with Anglo American's internal Technology Development Group. See *also* Deere & Company's joint development with University of Illinois as evidenced in jointly assigned United States Patent Nos. 7,587,081; 8,712,144; 8,737,720; and 8,855,405; and Deere & Company's joint development with Kansas State University as evidenced in the jointly assigned United States Patent Nos. 7,792,622; 7,684,916; 7,580,549; and 7,570,783; and MAKO Surgical Corp.'s joint development with the University of Florida as evidenced in jointly assigned United States Patent Nos. D625,415 and D622,854.

Although universities may be more willing to focus on research and development that does not necessarily have near term commercialization potential, it does not mean that universities do not seek protection for their inventions, nor does it mean that such research does not directly lead to new robotics products or robotics companies. Indeed, universities conducting research in the field of robotics frequently patent inventions. Additionally, there exist, as of the date of this report, numerous companies within the robotics industry that are "spinoffs" or "spinouts" of research and development projects conducted at universities.[34]

When it comes to inventive robotics firms, three main types can be identified.

First, there are small company startups or specialized robotics firms which are often created by individual inventors affiliated to academic robotics centers or robotics clusters, sometimes with significant direct or indirect government support. An example is Universal Robots, which emerged from a robotics cluster in Demark with links to the Danish Technological Institute, receiving initial government and seed funding.

Although parts of the industry are more mature today, the potential for small robotics startups is still large. In the early stage of radical innovation, small startups demonstrate more agility and speed, and closer interaction with academia. Also, innovation ecosystems are becoming more specialized, allowing for niche specialist companies. Third-party external developers are increasingly part of the robotics innovation system, as robotics platforms, often based on open-source software architectures, are the starting point for further development. Also, a growing number of companies provide robotics-related services – mobility or machine management systems. Moreover, the rise of new, more consumer-oriented robotics firms and new funding mechanisms allow for small initial start-ups. Play-i, now called Wonder Workshop, for instance, which focuses on creating educational toy robots, recently raised money through crowd-funding platforms.

Second, large, established robotics companies, initially focused on industrial robot research and production alone, such as ABB (Switzerland), Kawasaki Heavy Industries, Yaskawa and Fanuc (Japan) and KUKA (Germany) are active in robotics R&D. Scale matters, as innovating in the field of industrial robotics hardware is particularly capital-intensive; research takes years to materialize. Large clients in the automotive sector, for instance, are only willing to buy from large, trusted, established companies to avoid safety risks. In addition, large robotics firms are emerging from the novel trend toward service and household robots. iRobot (US) is one such example. Initially a spin-off from MIT, it is now a large company producing robots for business, private households and for security purposes, although still making most of its revenue from the development and sale of robots for military applications.

[34] See Rory Cellan-Jones, *Oxford's robots and the funding of innovation*, BBC.com, November 3, 2014. Startup companies in the robotics field that are spinoffs/spinouts of research conducted in a university setting are common in the United States, but also occur with some frequency in European and Asian nations. Examples include Oxbotica (a spinout of Oxford University), Empire Robotics (a spinoff of Cornell University), Blue Belt Technologies, Inc. (a spinoff of Carnegie Mellon University), Meka Robotics (a spinoff of Massachusetts Institute of Technology and acquired in late 2013 by Google), Medrobotics Corp. (a spinoff of Carnegie Mellon University and recently raised 20,000,000.00 USD in a Series F funding round), Schaft Inc. (a spinoff of University of Tokyo and acquired in late 2013 by Google), RE2, Inc. (a spinoff of Carnegie Mellon University), and Autonomous Solutions, Inc. (a spinoff of Utah State University).

Third, large firms outside the robotics industry have also gained related competencies. Firms such as BAE Systems (UK) in the area of defense, aerospace and security have always and continue be important players for robotics innovation. In addition, firms in the automotive sector continue to be significant, not least due to their own important use of robots. A newer development is the increasing involvement of electronics and ICT firms such as Samsung (Republic of Korea) and Dyson (UK). As robotics becomes more reliant on connectivity and ICT networks, Internet or IT-related firms such as Amazon, Google and Facebook but also the Indian ICT services firm Infosys, Alibaba of China and Foxconn of Taiwan Province of China are joining the fray, often acquiring shares in or taking full ownership of established robotics firms. Moreover, firms in the health sector are also increasingly prominent in robotics research. Market leaders in the area of surgical robots, for instance, include Intuitive Surgical, Stryker and Hansen Medical.

As the advantages of robotics have become increasingly visible to non-robotics companies, there has been an increased focus on traditional companies obtaining the advantages of robotics capabilities applicable to their business. Such a desire to embrace robotics technology has materialized into significant strategic business decisions, including, acquisitions of robotics companies whose technology will likely directly benefit the acquiring company's business and/or risk replacing the acquiring company's business,[35] traditional companies entering into joint development agreements with robotics companies for the purpose of developing robotics solutions aimed at the traditional companies' business,[36] traditional companies creating their own internal robotics divisions through the hiring of individuals with robotics experience,[37] and the formation of strategic alliances for the purpose of creating a new robotics ecosystem or "cluster".

There are also recent examples of private companies attempting to tackle particularly difficult problems in the robotics industry by using monetary incentives in a similar crowdsourcing competition program akin to that of competitions organized by governments. For example, in September 2014, Amazon.com Inc. announced the "Amazon Picking Challenge", which "challenges" company and university teams to solve the complicated problem of warehouse picking.[38] This type of "challenge" is similar to the open entry competitions known as the United States' DARPA Robotics Challenge or the prior DARPA Grand Challenge.

[35] Notable examples of traditional companies acquiring robotics companies include (i) Amazon.com Inc.'s acquisition of Kiva Systems, Inc., See John Letzing, *Amazon Adds That Robotic Touch*, The Wall Street Journal, March 20, 2012 discussing Amazon.com Inc.'s acquisition of Kiva Systems, Inc.; (ii) Stryker Corp.'s acquisition of MAKO Surgical Corp., See Joseph Walker, Tess Stynes, *Stryker to Acquire Mako Surgical for About $1.65 Billion*, The Wall Street Journal, September 25, 2013 discussing Striker's acquisition of MAKO Surgical Corp.); and (iii) Advantech Co.'s acquisition of LNC Technology, See Kevin Chen*, Advantech buys majority stake in LNC*, Taipei Times, August 31, 2013 (discussing Advantech Co.'s acquisition of a majority of the shares of LNC Technology.

[36] Notable examples of traditional companies entering into joint development agreements with robotics companies for the purpose of developing robotics technology directly applicable to the traditional company's business include (i) Anglo American's partnership with Autonomous Solutions, Inc.; (ii) Lowe's Companies, Inc.'s partnership with Fellow Robots; and (iii) John Deere's joint development with iRobot Corporation, whose joint inventions can be noted in jointly assigned patents (See United States Patent Nos. 8,874,300; 7,894,951; 8,020,657; and 8,473,140).

[37] See George Anders, *Amazon's Drone Team Is Hiring: Look At These Nifty Job Ads*, Forbes, May 19, 2014 discussing Amazon.com Inc.'s job postings seeking individuals with experience relevant to its then-recently formed drone division.

[38] Joe Romano, *Amazon Picking Challenge*, RoboHub, November 4, 2014; See *also* Merce Gamell, *Crowdsourcing for Designing the New Amazon Robots*, ARISPlex, November 20, 2014.

Both from publicly available information concerning formal partnerships and joint development agreements, as well as from an analysis of patent filings covering robotics technology,[39] there is sufficient evidence to observe a significant degree of collaboration on the development of robotics technology. There are several reasons why there is a greater amount of collaboration in the robotics industry than in many other industries.

First, when it comes to government contracts, and in particular, defense contracts with the United States Government, the contracted project is sometimes divided among more than one robotics company. For example, the government will frequently award the design and fabrication of the mechanical and electrical aspects to one company, but require the software to be designed and built by a different robotics company.[40]

Second, the problems that robotics companies tackle are often extremely complex in multiple disciplines. As a practical matter, most small and midsize robotics companies do not have experts in all of the engineering disciplines necessary to build all aspects of a sophisticated robot. The complexity of the technological challenges applicable to many of the robotics products being developed is one reason that even well-capitalized robotics companies enter into joint development agreements with other robotics companies.[41]

Third, customized autonomous systems are now a common site in medical device companies, pharmaceutical companies, and laboratories. Some companies and labs have an internal robotics and automation group that will work on certain projects independently, but who will also collaborate with specialized robotics companies when presented with a particularly time consuming or otherwise challenging assignment.[42]

The high degree of collaboration surrounding the development of robotics technology suggests that joint development projects, as well as personal contacts, are both meaningful mechanisms and avenues through which knowledge and skills relevant to robotics technology is diffused. Although the degree to which such knowledge and skills are also diffused through scientific publications and the publications of patent applications is unknown, this report's author is confident that both types of publications are a mechanism used within the robotics industry for acquiring knowledge of technological developments within the industry.[43]

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[39] See UKIPO (2014), p. 13-16 observing that the data obtained from patent filings corroborates the conclusion that there is a substantial amount of collaboration within the robotics industry.

[40] See, as an example, Robotics Trends Staff, *Autonomous Solutions Awarded Contract to Develop an Immersive UI*, Robotic Trends, July 5, 2007.

[41] Notable examples of joint development agreement between robotics companies includes iRobot Corporation's joint development and licensing agreement with InTouch Technologies Inc. d/b/a InTouch Health, See iRobot Press Release, *iRobot and InTouch Health Announce Agreement*, July 20, 2011; See *also* InTouch Health Press Release, *iRobot and InTouch Health Announce Agreement To Explore Potential Opportunities in Healthcare Market*, July 20, 2011; See *also*, as evidence of the joint development between iRobot and InTouch, jointly assigned United States Patent No. 8,718,837.

[42] Although internal robotics and automation divisions within traditional companies are not necessarily publicly promoted, a search of robotics-focused patents assigned to traditional companies outside the technology industry demonstrate that robotics related innovation is at least occurring within traditional companies in areas relevant to those companies' business. See, as examples, robotics and automation related patents assigned to Pfizer Inc; see*, e.g.,* United States Patent Nos. 5,370,754; 6,489,094); Abbott Laboratories (see*, e.g.,* United States Patent Nos. 6,588,625; 8,318,499; and Deere & Company. see*, e.g.,* United States Patent Nos. 7,861,794; 8,195,342; 8,295,979; and 8,874,261.

[43] As part of the qualitative research conducted for this report, C. A. Keisner conducted informal interviews with directors of IP for numerous prominent robotics companies. Among the information collected from such informal interviews, was that several robotics companies regularly monitor the patent applications published by their competitors. Regularly monitoring the patent applications of competitors at the time such applications are published is perceived by those doing such monitoring to serve three primary purposes, including, (i) learn of new developments in technology relevant to their business, (ii) obtain insight into a competitor's plans to either

Generally speaking, the exchange of knowledge within the robotics ecosystem currently seems extensive and fluid. This is benefited by the science-intensive nature of robotics innovation and the strong role of science and research institutions, but also the admittedly nascent phase of many advanced robotics strands. Scientific papers and conferences – such as the International Symposium on Industrial Robots – play a key role in the transfer of knowledge. Moreover, robotics contests and prizes rewarding solutions to specific challenges enable researchers to learn and benchmark their progress, and to close the gap between robotics supply and demand. Collaboration among the three types of firms mentioned above is extensive.

Finally, decentralized, software-enabled innovation is likely to increase in the future as robots become more widespread, and robot platforms and systems more standardized. In practice, a wider set of external firms and partners will be able to deliver customized solutions to existing proprietary robotic software platforms. This will enable greater modularity in innovation.

### 3.3 The extensive role of government in orchestrating and funding innovation

Governments and their institutions have played a large role in supporting robotics innovation. The standard set of technology-neutral government innovation policies has strongly supported robotics innovation, in particular through supply-side policies taking the form of research funding or support for business R&D.

In particular government-funded military technology advancements that, while kept confidential for years, are ultimately disclosed and contribute to the progress of the robotics industry.[44] Advanced technologies, although originally developed for military applications, are often utilized by the private sector for non-military commercial purposes.

Beyond important research funding and standard innovation support measures, a few specific support measures deserve mention:

**Creation of special research institutions or research networks:** Examples include the Swiss National Centre of Competence in Research Robotics, which federated research labs, and the Korea Robot Industry Promotion Institute, set up to promote technology transfer.

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improve an existing product or create a new product, and (iii) learn if a competitor is attempting to obtain patent protection concerning something that should be challenged as either non-novel or obvious. However, it is not merely competing robotics companies who monitor the publication of patent applications in order to be aware of technological developments in the robotics industry. Indeed, when a patent application is published concerning an invention of particular interest, especially when it relates to a potentially transformative technology and/or indicates a potentially shift in direction for a company well-known to the public, it is not uncommon for the patent application to become the subject of an article. See*, e.g.,* Jason Falconer, *Patent Suggests Sony Still* Sees *Future for Household Robots*, IEEE Spectrum, April 14, 2014 discussing Sony Corporation's potential strategy to develop personal robots based on the publication of United States Patent Application No. 2014/0074292, filed on April 16, 2012, entitled "Robot device, method of controlling robotic device, computer program, and program storage medium".

[44] See Springer (2013), p. 15-16 discussing the development and use of drones for military purposes in the 1970s.

**R&D funding, grants and public procurement:** Governments, and often the military, fund robotics innovation and create demand by the means of grants or – often pre-commercial – procurement. In the US, R&D contracts, including from the National Institutes of Health or DARPA, are the foremost catalysts.[45] Pre-commercial procurement of robotics solutions for the healthcare sector, for instance, is part of EU Horizon 2020 grants. Governments have also incentivized innovation and advancement within the robotics industry through various types of incentive programs. In the United States, for example, the government incentivized private companies and universities to create autonomous vehicles by offering a substantial monetary sum to whomever accomplished a set task.[46] Other governments have provided tax breaks for robotics companies, although some may argue that such incentives primarily incentivize the relocation of robotics companies rather than fostering innovation. Yet, still other countries, whether focused specifically on robotics or not, provide grants allowing prototype-stage products to be used within an industry with potential customers, thereby alleviating the particularly lengthy time gap for robotics companies between the creation of a functional prototype and a commercialized product that has been more rigorously tested and satisfied arduous regulatory requirements.[47]

**Organizer of contests and challenges and prizes:** Governments have played a role as organizer of robotics contests. Japan has announced a Robot Olympics, the UK recently held a competition for driverless vehicles and the DARPA Robotics Challenge is a landmark.

**Incentives for collaboration, technology transfer, finance and incubation:** Through grants or contracts, governments will frequently require collaboration and technology transfer. The EU Horizon 2020 Robotics project, for instance, stimulates public-private collaborative projects of a multi-disciplinary nature. In addition, government activities aim to facilitate cluster development, entrepreneurship and industry networking. Governments also ease the financing of robotics innovation, for example, the French government's seed fund "Robolution Capital".

[45] Mireles (2006), Springer (2013) and Siegwart (2015).

[46] See Mireles (2006) discussing the incentive scheme created by the United States' Department of Defense's research arm, the Defense Advanced Research Projects Agency (DARPA), with the goal of furthering the advancement of driverless vehicles.

[47] See Technopolis and University of Manchester (2011).

**Regulations and standards:** Finally, regulations created by governments, in the form of standards, testing and security regulations, impact the diffusion of robotics technology. Legal scholars disagree about the extent to which regulations actual spur or inhibit the growth of technological advancement in the robotics industry.[48] There does seem to be a general consensus that regulations have the potential to restrict such advancements.[49] One of the primary areas in need of attention is the reform of current safety standards applicable to robotics, particularly those requiring the clear separation of workspace between humans and robots.[50] The absence of reform to such safety standards, as may apply to other regulation, may hinder innovation and adoption of robotics technology.[51] Furthermore, governments can also hinder innovation in the private sector via burdensome regulations.[52] Yet, aside from the restricting regulation applicable to UAVs in several nations,[53] there is no regulation specific to most other robotics related technologies.[54]

In addition to the above, many high-income countries and China have announced special robotics action plans in recent years (see table 2). Mostly, these plans announce specific monetary investments in support of robotics research and innovation, including improving robotics education and technology transfer.

**Table 2: National robotics initiatives**

| Name of initiative | Country (Year of initiative) |
|---|---|
| National Robotics Initiative Advanced Manufacturing Partnership | US (2011) |
| France Robots Initiatives/*Feuille de Route du Plan Robotique* | France (2013/2014) |
| Robotics project Horizon 2020 | EU (2015) |
| New Industrial Revolution Driven by Robots ("Robot Revolution") | Japan (2015) |
| Next-Gen Industrial Robotization | Republic of Korea (2015) |
| Robotics technology roadmap in 13th Five-Year Plan (2016-20) | China (2015) |

Source: Authors based on national sources.

[48] See RoboLaw, Guidelines Regulating Robotics, p. 10 (2014) discussing the contradicting perceptions that premature and obtrusive legislation might hamper scientific advancement, with the perception that a lack of a "reliable and secure legal environment" may equally hinder technological innovation.

[49] See RoboLaw, Guidelines Regulating Robotics (2014); See *also, e.g.*, Ed Pilkington, *What's keeping America's private drone industry grounded?*, The Guardian, September 30, 2014 discussing the impact of regulation on the United States' drone industry.

[50] See Christensen, et al. (2013), p. 84 noting that "safety is a multidimensional issue extending beyond technology. It includes a number of governmental and industry standards as well as independent certification and liability exposure. These non-technical elements need to progress such that that clear standards exist for both professional and personal robotics providing all stakeholders with visibility needed for rapid innovation and adoption.".

[51] See Christensen, et al. (2013), p. 84 noting that the "current, limited set of standards for safety certification of both professional and personal robots, constrains innovation, reduces the pace of adoption, and adds costs.".

[52] See *Infra, Section II.B;* See *also Free the Drones,* The Economist, December 6, 2014; RoboLaw, Guidelines Regulating Robotics, p. 10 (2014).

[53] Regulations concerning UAVs exists in at least Canada, Australia, the United States, and the European nations whose airspace is regulated by the European Aviation Safety Agency.

[54] See Report of the Sixty-Eighth Session of the Working Party on Road Traffic Safety, Economic and Social Council, United Nations, ECE/Trans/WP.1/145, April 17, 2014 (proposing amendments to the 1968 Vienna Convention on Road Traffic in consideration of driverless/autonomous vehicle technology); See *also* Legislation in the United States concerning driverless cars, including enacted state legislation in California (SB 1298), District of Columbia (B19-0931), Florida (CS/HB1207), Michigan (SB 0169, 0663), and Nevada (AB 511, SB 140).

## 4. Robotics Innovation and Intellectual Property

The focus of robotics innovation is shifting from industrial automation to more advanced robotics involving various technological fields, actors and economic sectors. As a result, related IP and other strategies to appropriate returns on innovation investment are embryonic; our understanding of them is incomplete. Also, recognizing the broad scope of the robotics industry is important for this study because the large variety of robotics products and their applications means that there is no "one-size-fits-all" IP strategy for robotics companies, nor are observations and trends related to one segment of the robotics industry necessarily relevant to other segments of the robotics industry.

Some tentative findings on appropriation strategies do, however, emerge on the basis of the existing literature, data and insights from industry practitioners and robotics researchers.

### 4.1 The increasing role of patents, their function and potential challenges

Patents are a particularly important IP right for robotics companies because of the significant amount of capital frequently required for research and development prior to the manufacturing of a commercially ready product.

Indeed, the large pre-market research and development costs coupled with slow regulatory clearance can create a context in which trailblazing robotics companies feel required to turn to patent protection in order to recoup their investment. Absent this protection, newcomers would be able to enter the market, after the "trail has already been blazed", at a lower cost for research and development and have to overcome fewer regulatory hurdles.[55]

For inventions discoverable through reverse engineering or other legal means, patent protection is typically favored over trade secrets. It is understood that many robotics companies whose competitive advantage is perceived to be sophisticated software designed to enable robotic hardware devices may use software that is so complicated it cannot be easily reverse-engineered, which is something traditionally believed to be possible with software-based electro-mechanical devices.

Although deterring and excluding competitors is frequently a primary consideration of robotics startups, another common incentive for seeking patent protection concerns the perceived advantages to startups when seeking investments.[56]

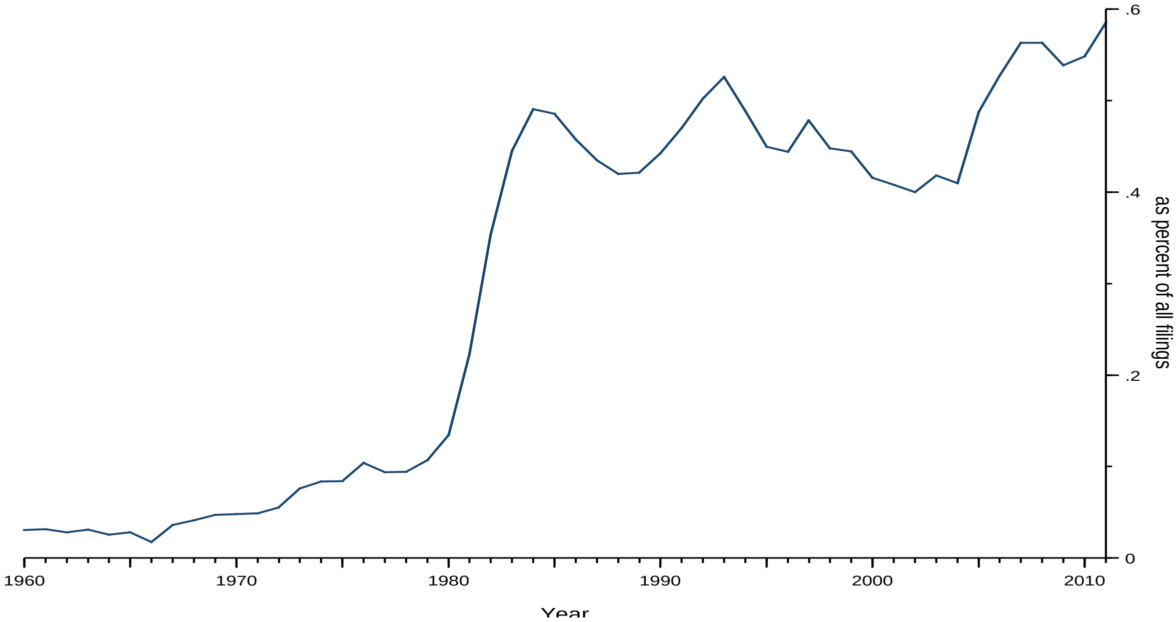
As a result, key robotics inventions were frequently patented by their original – often academic – inventor, who often also started a corresponding company or actively transferred the IP to existing manufacturing firms.

[55] See Cooper (2013), citing Casey Nobile & C. Andrew Keisner, *The IP Battle Continues for Robotics Companies: A Patent Attorney's Reprise of the VGo/InTouch Health Verdict and its Implications*, Robotics Business Review, January 7, 2013.

[56] See Keisner (2012); See *also* Eilene Zimmerman, *Why More Start-Ups Are Sharing Ideas Without Legal Protection*, The New York Times, July 2, 2014 mentioning that early-stage investors are generally reluctant to sign non-disclosure agreements and discussing the benefits of filing provisional patent applications in that context. This motivation for startups to file patent applications was corroborated by several directors of IP for robotics startups during informal interviews conducted by this report's author in connection with this report.

In sum, robotics patents increased strongly during the 1980s, as broad-based automation of factories flourished and robotics research was ramped up. Robotics-related first filings roughly quadrupled during this decade (see figure 3). More importantly, these filings outpaced patent filings from other technological fields. Robotics share of total patents increased from .13% in 1980 to 0.53% in 1993 (see figure 5). Then, after a relatively flat patenting activity during the 1990s and first half of 2000s, the shift to more advanced robotics has given another boost to robotics patenting which continues to this day. In a period of increasing overall patenting activity, robotics absolute patent filings roughly doubled and the share increased from .4% in 2004 to .6% in 2011 (see figure 5).

**Figure 5: Fast growth in robotics patenting, especially in the late 1980s and as of 2005**
**First patent filings by origin, 1960-2011, in percent of all filings**




Source: WIPO based on the PATSTAT database (see technical annex).

This picture of inventive activity concentrated in a few nations, also now broadening to include Asian innovative nations, is also mirrored by patent data. Earlier, Figure 3 depicted the number of first patent filings worldwide in the robotics space between 1960 and 2012. It shows the importance of US and European and later Japanese inventors at the outset, the emergence of the Republic of Korea in the early 2000s and more recently China.[57] While the share of Chinese patents in total robotics patents in 2000 was only two percent, that figure had risen to 37 percent by 2011. The Republic of Korea's share stood at 17 percent in 2011. Japan's share fell from 45 percent in 2000 to 10 percent in 2011.[58]

Figure 6 below indicates the origin of first patent filers in two periods, 1980-1990 and 2000-2012. In the more recent period, the countries with the highest number of filings are Japan, China, Republic of Korea and the US, which each filed more than 10,000 patents and together account for about 75 percent of robotics patents, followed by Germany with roughly 9,000 patents and France with over 1,500. Other countries such as Australia, Brazil, a number of Eastern European countries, the Russian Federation and South Africa also show newer robotics patenting activity, although on a low level.

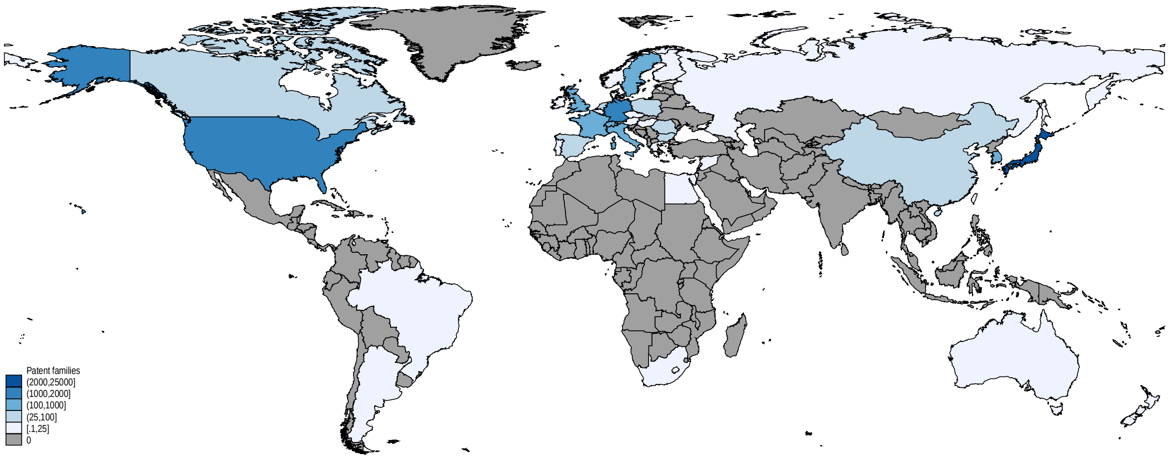
[57] See also UKIPO (2014).

[58] Note that proportions are calculated considering only first filings with at least one patent granted within the patent family.

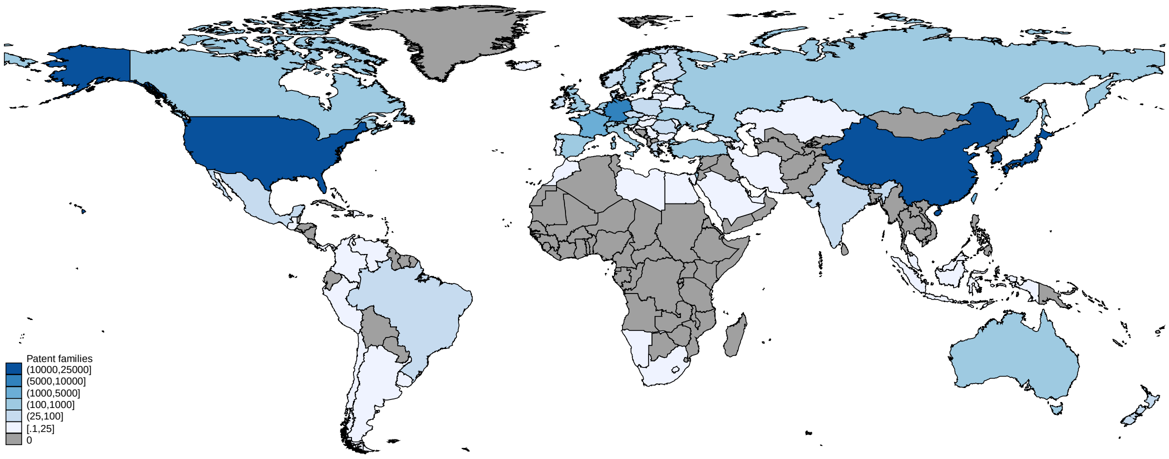
Indeed, in terms of robotics innovation and company startups, the majority of activity is in high-income countries, except for China again.

**Figure 6: Increasing but limited geographical diversity in robotics innovation**

*Number of first patent filings worldwide, 1980-1990*



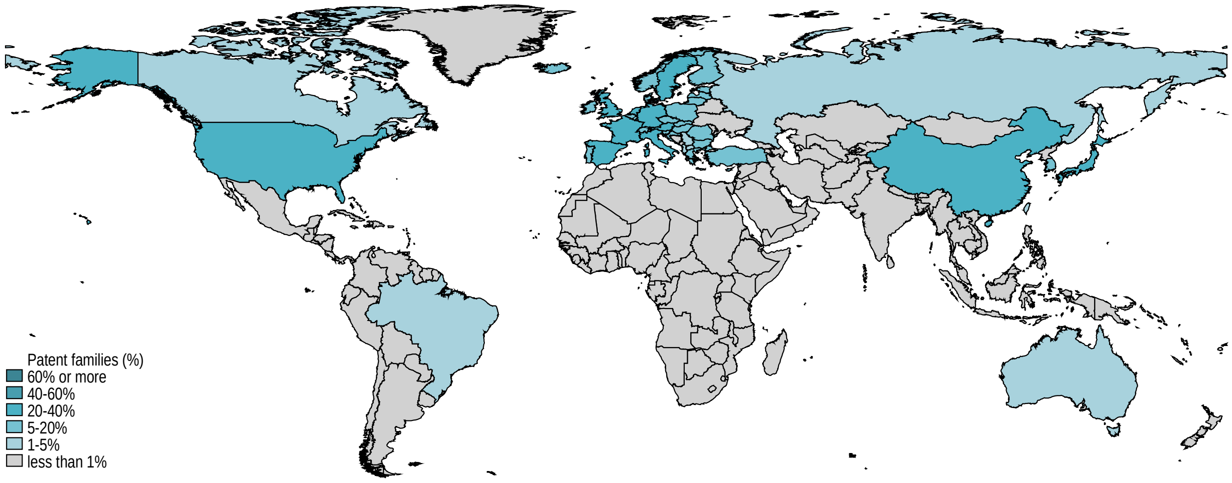

*Number of first patent filings worldwide, 2000-2012*




Source: WIPO based on the PATSTAT database (see technical annex).

Actual robotics patent exclusivity is geographically highly concentrated, namely in Japan as the leading destination with close to 39 percent of all robotics patents, the US and China with close to 37 percent, Germany with 29 percent, followed by other major European countries and the Republic of Korea. In turn, only 1.4 percent of robotics patents are filed on average in other low- and middle-income countries.

**Figure 7: Robotics patenting focused on a few selected destinations only**
**Share of robotics-related patent families worldwide for which applicants have sought protection in a given country**




Source: WIPO based on the PATSTAT database (see technical annex).

Automotive and electronics companies are still the largest filers of patents relating to robotics (see table 3), but new actors are emerging from different countries and sectors such as medical technologies. These firms' robotics patent portfolios are growing in size, as firms grow them organically or purchase companies with a stock of granted patents.

**Table 3: Top 10 robotics patent filers, 1995-onwards**

| Company name | Country | Number of first patent filings |
|---|---|---|
| Toyota | Japan | 4,189 |
| Samsung | Republic of Korea | 3,085 |
| Honda | Japan | 2,231 |
| Nissan | Japan | 1,910 |
| Bosch | Germany | 1,710 |
| Denso | Japan | 1,646 |
| Hitachi | Japan | 1,546 |
| Panasonic (Matsushita) | Japan | 1,315 |
| Yaskawa | Japan | 1,124 |
| Sony | Japan | 1,057 |

Source: WIPO based on the PATSTAT database (see technical annex).

The large and growing stock of patents owned by universities and PROs is noteworthy too. Table 4 lists the most important patent holders, now largely dominated by Chinese universities. While industry experts note a strong move towards "open source" in the young generation of roboticists at universities, the IP portfolios of universities are also growing strongly, possibly facilitating the commercialization of new technologies as described in earlier sections, but possibly also creating new challenges for universities and PROs in managing and utilizing these sizeable portfolios.

**Table 4: Top 10 robotics patent holders among universities and PROs, 1995-onwards**

| Top 10 patenting worldwide | | |
|---|---|---|
| Shanghai Jiao Tong University | 811 | China |
| Chinese Academy of Sciences | 738 | China |
| Zhejiang University | 300 | China |
| Korea Institute of Science and Technology (KIST) | 290 | Rep. of Korea |
| Electronics and Telecommunications Research Institute | 289 | Rep. of Korea |

| | | |
|---|---|---|
| (ETRI) | | |
| Tsinghua University | 258 | China |
| Harbin Engineering University | 245 | China |
| National Aerospace Laboratory | 220 | Japan |
| Harbin Institute of Technology | 215 | China |
| KAIST | 188 | Rep. of Korea |
| **Top 10 patenting worldwide (excluding China)** | | |
| Korea Institute of Science and Technology (KIST) | 290 | Rep. of Korea |
| Electronics and Telecommunications Research Institute (ETRI) | 289 | Rep. of Korea |
| National Aerospace Laboratory (JAXA) | 220 | Japan |
| KAIST | 188 | Rep. of Korea |
| Deutsche Zentrum für Luft- und Raumfahrt | 141 | Germany |
| Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung | 91 | Germany |
| University of Korea | 85 | Rep. of Korea |
| Hanyang University | 84 | Rep. of Korea |
| Seoul National University | 77 | Rep. of Korea |
| National Institute of Advanced Industrial Science and Technology (AIST) | 69 | Japan |

Note: Depending on the legislation and policy in place, academic inventors may file under their own name or the spin-off company name in certain countries (see WIPO, 2011). They are not captured here.
Source: WIPO based on the PATSTAT database (see technical annex).

It is challenging to understand the various factors leading firms in the field of robotics to file for patents, given the current evidence base. No large-scale survey of robotics firms or other solid quantitative work exists that would shed light on this question. Providing a definitive answer on the impacts of robotics patents on follow-on innovation via disclosure, licensing and IP-based collaboration is also difficult.

However, a number of findings emerge from the views of industry experts, including both lawyers and roboticists.

As in other high-tech sectors, and in anticipation of significant commercial gains from the robotics industry, robotics firms seek to use patents to exclude third parties, to secure their freedom to operate, to license and cross-license technologies and, to a lesser extent, to avoid litigation. For small and specialized robotics firms in particular, patents are a tool to seek investment or a means of protecting their IP assets defensively against other, often larger, companies.

In terms of the impacts of the patent system on innovation, at present the innovation system appears relatively fertile. Collaboration – including university–industry interaction – is strong, and there is extensive cross-fertilization of research. Patents seemingly help support the specialization of firms, which is important for the evolution of the robotics innovation system.

It is also hard to argue that patent protection is preventing market entry or restricting robotics innovation more generally by limiting access to technology. The available evidence shows little or no litigation occurring in the field of robotics. Indeed, most of the disputes over robotics IP in the past 10 years have involved just one company, iRobot.

The importance of particular patents for robotics innovation is hard to verify too. Currently, no patents have been flagged as standard-essential; no known patent pools exist in the area of robotics. And there are few formal and disclosed collaborations or exchanges in which IP is central. Only one major licensing deal in the recent history of robotics has received much attention.[59] That said, company acquisitions involving the transfer of IP are growing strongly.

As regarding disclosure, firms use patents to learn of new technology developments, to gain insight into competitors' plans to improve or create products, but also to learn if a competitor is attempting to obtain patent protection that should be challenged. Forward patent citations within and outside robotics are often used as a sign that incremental innovation taking place; earlier inventions are built upon. Often, however, and in particular in the US patent system, they are a mere legal obligation, making impact assessment more difficult. As a result, the overall value of patent disclosure in the area of robotics remains largely unassessed.

Many of the above questions will only be resolved over time. Arguably, IP is not yet fully used in advanced robotics and so its potential impact remains to be realized. Compared with the standard industrial robot innovation of the past, today's robotic innovation system involves more actors, various technology fields and significantly more patent filings. One can start to see the more intensive offensive and defensive IP strategies that are present in other high-technology fields.

[59] The most prominent agreement in recent history was the July 2011 joint development and cross-licensing deal between iRobot Corp and InTouch Technologies.

A vital question is whether the increased stakes and commercial opportunity across various sectors will tilt the balance toward costly litigation, as in other high-tech and complex technologies. For the moment the number of IP disputes involving robotics companies is too small to extract any meaningful insight about the effectiveness of the IP system. One noticeable trend is also that the majority of IP disputes over the past ten years involved a single well-known United States based robotics company, including a 2005 lawsuit captioned *iRobot Corp. v. Koolatron & Urus Indus.*¸[60] a 2007 lawsuit captioned *iRobot Corp. v. Robotic FX*,[61] a 2013 lawsuit in Germany captioned *iRobot v. Elektrogeräte Solac Vertrieb GmbH, Electrodomésticos Solac S.A, Celaya, Emparanza y Galdos Internacional S.A, and Pardus GmbH*,[62] and another 2013 lawsuit in Germany captioned *iRobot v. Shenshen Silver Star*.[63] There was also only one recent IP dispute in which the lawsuit went to a final judgment and appeal,[64] which makes it difficult, if not impossible, to assess whether the judicial system adequately resolves IP disputes involving robotics related technologies.

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[60] In 2005, iRobot sued a Canadian company, Koolatron & Urus Indus., over its vacuum robot. iRobot asserted several different types of IP claims including patent infringement, copyright infringment, and infringement of the Roomba's trade dress. iRobots' Roomba, at the time of this lawsuit, was a round floor vacuum in grey and white, whereas Koolatron's vacuum robot was also round, but with yellow and black color. See *iRobot Corporation v. Urus Industrial Corporation, et al.*, 1:05-cv-10914 (D. Mass. 2005). The patents that iRobot alleged to be infringed by Koolatron & Urus Indus. were United States Patent Nos. 6,594,844 and 6,883,201. This case quickly settled, but the parties entered into a consent judgment with three main points. First, it said iRobot's patents are valid and enforceable. This consent judgment may not have an impact on other vacuum robot companies, but it probably prevents Koolatron from ever arguing otherwise. Second, Koolatron agreed not to sell its vacuum robot in the United States. And Finally, Koolatron agreed to not advertise in any way that dilutes iRobot's reputation or products. See Order Entering Consent Judgment, dated August 10, 2005, filed as Dkt. No. 2 in *iRobot Corporation v. Urus Indus. Corp., et al.*, 1:05-cv-10914 (D. Mass. 2005).

[61] In 2007, a former iRobot employee started a new company called Robotic FX, which created a robot for military mine detection that was similar to the robot he developed while he was an employee at iRobot. After Robotic FX won a lucrative government contract by slightly underbidding iRobot, iRobot filed two lawsuits against Robotic FX and its founder for trade secret misappropriation and patent infringement. See *iRobot Corporation v. Jameel Ahed and Robotic FX, Inc.*, 1:07-cv-11611 (D. Mass. 2007) (lawsuit filed in the United States District Court for the District of Massachusetts by iRobot against Robotic FX and its founder for trade secret misappropriation); *iRobot Corporation v. Robotic FX, Inc.*, 2:07-cv-01511 (N.D. Ala. 2007) (lawsuit filed in the United States District Court for the Northern District of Alabama by iRobot against Robotic FX for infringement of United States Patent Nos. 6,263,989 and 6,431,296). The patents asserted by iRobot covered tread wheels in the front that swiveled, which was used on both robots. This case was an extremely public and high profile case, but it ultimately settled with some harsh consequences for Robotic FX and its founder, which included liquidating Robotic FX and its founder agreeing not to work in the industry for five years. See Order Entering Stipulated Consent Judgment and Proposed Permanent Injunction, dated December 21, 2007, filed as Dkt No. 88 in *iRobot Corporation v Jameel Ahed and Robotic FX, Inc.*, 1:07-cv-11611 (D. Mass. 2007). Additionally, the lucrative contract that Robotic FX seemingly won by underbidding iRobot, did in the end, go to iRobot.

[62] In July of 2013, iRobot filed a patent infringement lawsuit in the District Court of Düsseldorf against Elektrogeräte Solac Vertrieb GmbH and three other companies, alleging that their vacuum robot, the Solac Ecogenic AA3400, infringed upon five iRobot owned European patents. See Hiawatha Bray, *Patent lawsuit targets four iRobot rivals*, The Boston Globe, July 2, 2013. The patents that iRobot asserted in this lawsuit were EP 1 331 537 B1, EP 2 251 757 B1, EP 1 969 438 B1, EP 1 395 888 B1 and EP 1 776 623 B1. *Id.*

[63] In September 2013, iRobot filed a patent infringement lawsuit in the District Court of Düsseldorf against Chinese-based companies Shenzhen Silver Star Intelligent Technology Co. Ltd. and Shenzhen Silver Star Intelligent Electronic Ltd. iRobot alleged that the Shenzhen Silver Star companies' vacuum robot infringed on four of iRobot's European patents. Since iRobot was able to obtain a preliminary injunction against the Shenzhen Silver Star companies based on its allegations of patent infringement, German [customs] officials seized the robotic vacuums that the Shenzhen Silver Star companies were presenting at the 2013 IFA consumer electronics trade show in Berlin, Germany. See RBR Staff (2013); See *also* Patricia Resende, *Robot parts seized at trade show after iRobot takes legal action against Chinese firm*, BizJournals.com, September 6, 2013 (article including picture of customs officials seizing robotic floor vacuums from IFA consumer electronics trade show); Mike Davin, *Robots taken from trade show after iRobot obtains injunction*, TheBusinessOfRobotics.com, September 6, 2013.

[64] InTouch Health and VGo Communications both independently developed telepresence robots and did not appear to clash until VGo started to use its telepresence robot in hospitals. InTouch's telepresence robot is designed for hospitals and has specific features for doctors that VGo's telepresence robot does not. But VGo's telepresence robot is a fraction of the price. Regardless of whether these robots are actually in competition for

There have also been cases – though not many to date – in which non-practicing entities have targeted robotics companies with a lawsuit.[65] In particular, press reports mention the possibility of negatively perceived patent troll activity in the field of surgical robots and medical robotics more broadly.

Two elements could increase the likelihood of disputes. First, experts consulted in the course of research for this report have raised concerns that overly broad claims are being made in the case of robotics patents, especially with respect to older patents. While patent infringement disputes between robotics companies appear to be resolved effectively by current judicial systems,[66] certain patent infringement disputes have led some professionals within the robotics industry to question the breadth of patent claims contained in older patents.[67]

Second, in certain countries the patentability and novelty of computer-related inventions generally are a matter of debate. This is particularly true in the US, where the recent Supreme Court decision in *Alice Corp. v. CLS Bank* seems to have reinforced a restrictive approach on the patent eligibility of software.[68] Given the large and growing software-related component of robotics innovation, concerns about software patentability may pose a challenge in relation to current and future robotics-related patents.

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the same potential customers, InTouch sued VGo on [date] for patent infringement and on [date] the jury came back with a full victory for VGo, finding the patents were both not infringed and invalid. See Nobile (2013). The Court of Appeal for the Federal Circuit affirmed the jury's decision on non-infringement, but reversed on the issue of the patent's validity. See *InTouch Technologies, Inc. d/b/a InTouch Health v. VGo Communications, Inc.*, 751 F.3d 1327 (Fed. Cir. 2014). It is important to note the significance of this decision in light of the growing number of telepresence robots that are already on the market or soon will be. See Nobile (2013) discussing ramifications of the jury verdict in the *InTouch Technologies, Inc. v. VGo Communications* lawsuit as it pertains to other telepresence robotics companies. For such companies, decisions like this are important to their future both in terms of future markets and their ability to obtain funding.

[65] See e.g., Roy-G-Biv. Corp. v. Fanuc Ltd., 07-cv-00418 (E.D. Tx. 2007) (asserting infringement of United States Patent Nos. 5,691,897; 6,513,058; 6,516,236; and 6,941,543); see also Roy-G-Biv Corp. v. ABB, Ltd., et al, 11-cv-00622 (E.D. Tx. 2011) (asserting infringement of United States Patent Nos. 6,513,058 and 6,516,236); Roy-G-Biv Corp. v. Honeywell Int'l, Inc., et al., 11-cv-00623 (E.D. Tx. 2011) (asserting infringement of United States Patent Nos. 6,513,058; 6,516,236; and 8,027,349); Roy-G-Biv Corp. v. Siemens Corp., 11-cv-00624 (E.D. Tx. 2011) (asserting infringement of United States Patent Nos. 6,513,058 and 6,516,236). For the purpose of the discussion in this report, patent infringement lawsuits against robotics companies that concern technology not specific to robotics are not considered. See, e.g., Hawk Technology Sys., LLC v. Fanuc Robotics Corp., 13-cv-15234 (E.D. Mich. 2013) (asserting infringement of United States Patent Nos. RE43,462 and 5,265,410 covering video recording and storage technology); Landmark Technology, LLC v. iRobot Corporation, 13-cv-00411 (E.D. Tx. 2013) (asserting infringement of United States Patent Nos. 5,576,951 and 7,010,508 concerning internet based e-commerce technology).

[66] It should be noted that, for the purpose of this report, effective resolution of an IP dispute does not take into consideration the resources expended by companies in asserting or defending against a claim, which varies greatly amongst countries based on differences in judicial systems, including, for example, the large difference in resources expended in a lawsuit based on discovery rules and whether there exist fee-shifting rules.

[67] See*, supra*, discussion of *InTouch Technologies v. VGo Communications*; See *also* Frank Tobe, *The patent grip loosens*, Everything-Robotics, December 6, 2012 discussing aggressive patent strategies by InTouch and Intuitive Surgical, both robotics companies in the healthcare industry, and stating that others suggested such companies were asserting patents to broad to be valid in order to protect their market share.

[68] Thayer, L., and Bhattacharyya, A., Patent Eligibility of Software in the Wake of the Alice Corp. v. CLS Bank Decision, *Robotics Business Review*, August 14, 2014, and Thayer, L., and Bhattacharyya, A., Will Supreme Court Rein in Software Patents? *Robotics Business Review*, March 4, 2014.

### 4.2 Robotics platforms and the coexistence of IP and open source

As described in section 3 robotics platforms used in universities and businesses are increasingly central to robotics innovation. Increasingly, too, they are open platforms, often based on open-source software such as the Robot Operation System (ROS). These open-source robotics platforms invite third parties to use and/or improve existing content without the formal negotiation or registration of IP rights. Instead, software or designs are distributed under Creative Commons or GNU General Public License, a free software license. This allows for rapid prototyping and flexible experimentation.

The idea is simple. Actors distinguish between two levels of innovation. On the one hand, there is the collaborative development of robotics software, platforms and innovation. Such innovation may be substantial, but it is essentially precompetitive because the fields of use are relatively basic and do not serve to differentiate products. Actors therefore apply cooperative open-source approaches to obtain common robotics platforms, as this allows them to share the substantial up-front investment, avoid duplication of effort and perfect existing approaches.

On the other hand, however, innovative firms invest in their own R&D efforts and look to protect their inventions far more vigorously when it comes to those elements of robotics innovation that differentiate end-products.

This parallel application of cooperative and competitive approaches results in a coexistence of competitive and open source-inspired approaches to handling IP.

Various non-profit organizations and projects support the development, distribution and adoption of open-source software for use in robotics research, education and product development. The iCub, for instance, is an open-source cognitive humanoid robotics platform funded by the EU which has been adopted by a significant number of laboratories. Poppy is an open-source platform developed by INRIA Bordeaux for the creation, use and sharing of interactive 3D-printed robots. Other examples include the Dronecode project and the NASA International Space Apps Challenge.

Some of this will entail an increasing shift toward engaging end-users or amateur scientists to interact and improve on existing robotics applications. In fact, many user-oriented low-cost platforms built for home or classroom use, like TurtleBot and LEGO Mindstorms, are built on open-source platforms.

This open-platform approach is not limited to software; it can also encompass blueprints such as technical drawings and schematics, including designs. The Robotic Open Platform (ROP), for instance, aims to make hardware designs of robots available to the robotic community under an Open Hardware license; advances are shared within the community.

In general, it will be interesting to see how well the robotics innovation system can preserve its current fluid combination of proprietary approaches for those aspects of IP where the commercial stakes are higher plus non-proprietary approaches to promote more general aspects of relevant science through contests but also collaboration among young roboticists and amateurs interested in open-source applications.[69]

[69] In light of the high degree of collaboration in the robotics industry, as well as many nations' interest in fostering robotics innovation, it is timely for nations to re-examine their laws on joint IP ownership. Many nations' laws on joint IP ownership produce unexpected and unfair results in practice, unless the persons or entities involved contract around such laws.

### 4.3 Protecting robotic breakthroughs via technological complexity and secrecy

Potentially more important than patents, the technological complexity and secrecy of robotics systems are often used as a key tool to appropriate innovation. This is true for standard mechanical, hardware-related components.

There are multiple reasons why a robotics company may prefer to keep certain technologies or information as trade secrets rather than seeking patent protection. The first two reasons, which are not necessarily unique to robotics, are based on either the inability to obtain patent protection or it is believed that the IP cannot be reverse engineered by even the most sophisticated competitors. This is frequently done with robotics companies who believe that their manufacturing process could not be identified without a competitor actually observing the manufacturing process. The same is frequently true for the methods of testing a robot's performance. Some robotics companies have also survived with relatively few competitors and have the opinion that their work, although comprised of software and hardware, is so advanced that only a select few could reverse engineer their products.

Robotics companies that make a limited number of highly expensive robots, including for military applications, typically do not fear that competitors will gain physical possession of such robots to reverse engineer them. As such, reverse engineering may be difficult for that practical reason as well.[70]

Additionally, many small and mid-size robotics companies prefer trade secrets because they want to avoid the costs and fees that come with filing patent applications.

There are also historical reasons why robotics companies choose to retain information as trade secrets. In the 1980s, robotics made several significant advances and firms filed a large number of patents (see figures 3 and 5). However, few of these inventions were commercialized quickly. As a result, firms spent large amounts of money to obtain patents that expired before their products were commercialized. They learned from this experience that patents can be costly without necessarily bringing any reward, especially for innovations that may be decades away from use in a market-ready product.

Trade secret protection is also important when employee mobility is high. Robotics companies have sought to protect their trade secrets when an employee joins a competitor.[71] Many robotics companies bolster the protection of their trade secrets with restrictive covenants to the extent the relevant jurisdiction permits.[72]

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[70] See Keisner (2013b).

[71] See e.g. supra, MAKO Surgical Corp.'s lawsuit against Blue Belt Technologies and an employee who left MAKO Surgical for a position at Blue Belt; see also, e.g., supra ISR Group's lawsuit against Manhattan Partners.

[72] See Keisner (2013a) discussing, among other topics, trade secrets and the use of non-compete agreements within the robotics industry. One such example is the 2013 lawsuit *ISR Group v. Manhattan Partners*. Based on the documents filed in the lawsuit, it appears that ISR Group and Manhattan Partners were in serious talks about a potential acquisition, but after the deal fell apart and two ISR employees left to join Manhattan Partners, ISR sued for trade secret misappropriation in Tennessee state court. Manhattan Partners quickly removed the case to federal court, and then the parties settled. This shows the important trend of robotics companies' increasing willingness to defend their trade secrets through litigation when necessary. Another example is the 2013 lawsuit *MAKO Surgical v. Blue Belt Technologies*. MAKO Surgical filed a lawsuit in March of 2013 against Blue Belt Technologies and Blue Belt's then-recently hired employee for trade secret misappropriation and for the employee's violation of his contractual non-compete obligations to his former employer, MAKO. See *The Sincerest Form of Flattery…*, Robotics Business Review, March 21, 2013 (discussing the allegations in MAKO Surgical's trade secret misappropriation and breach of contract complaint against Blue Belt Technologies). MAKO obtained a preliminary judgment against Blue Belt Technologies and its employee (See *MAKO Wins Permanent Injunction Against Blue Belt Technologies*, Robotics Business Review, April 9, 2013), which prevented that employee from working for Blue Belt Technologies for a certain period of time. See Keisner (2013a). However, it should also be noted that, after MAKO Surgical' s lawsuit against Blue Belt Technologies

Finally, the more recent questions around the patentability of software in the US and elsewhere could increase the incentive to protect related inventions via secrecy instead.

### 4.4 The role of being first-to-market, reputation and strong brands

Being first to market, a strong after-sales service, reputation and brand have all been critical in past robotics innovation, and they remain so today – all the more so as the industry moves out of factories and into applications with direct consumer contact.

In the case of industrial automation, only a few trusted operators able to produce a large number of reliable robots and to service them dependably were in demand by automotive companies. Initially, Unimation dominated the supply of industrial robots; later, large firms such as Fanuc held sway.

While the landscape is more diverse today, being first and having a solid reputation and brand continue to be critical. Actors such as hospitals, educational institutions and the military will want to rely on experienced robotics firms and trusted brands. In the area of medical robot makers, examples are the DaVinci surgical robot, the CorPath vascular surgery robots and the Accuray CyberKnife Robotic Radiosurgery System. Even in fields related to military or similar applications, brands matter, as evidenced by the use of trademarks such as Boston Dynamics' "BigDog". But strong brands are particularly important when robots are sold directly to end-users; for example, the "Roomba vacuum cleaner" relies strongly on its trademark value.

Most robotics companies trademark their company names and robot names, with the result that a growing number of trademarks include the term "robot".

### 4.5 Industrial design rights, trade dress, and robotics

Next to patents, industrial designs protecting the ornamental features of a robot – as registered IP forms – also play an important role in helping firms appropriate the returns to their investments in R&D.

Another form of IP is trade dress, a source-designating type of IP that refers generally to the total image of a product.[73] Within the robotics industry, trade dress is a right generally used to describe the total image of a robot or robotics product.[74] Although some nations do not distinguish between trade dress rights and trademark rights, as both are source-identifying forms of IP, some nations provide protection for trademark rights under a sufficiently broad definition that it is perceived as extending to other source-identifying forms of IP, including registered trade dress rights.[75]

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for trade secret misappropriation was settled, MAKO Surgical again sued Blue Belt Technologies in June 2014 for patent infringement. See Cole E., "MAKO Surgical Sues Blue Belt Technologies", *Robotics Business Review*, June 10, 2014.

[73] See Reese (1994); See *also* United States Patent and Trademark Offices' Trademark Manual of Examining Procedure (2014), Section 1202.02, entitled "Registration of Trade Dress.".

[74] Similar to trade dress rights, industrial design rights protect the visual design of an object. As a result of The Hague Agreement Concerning the International Deposit of Industrial Designs, there is now a procedure for international registration of an industrial design, effective in several countries, via a single application. See WIPO (2014).

[75] See India's Trade Marks Act, 1999; see also Tiwari (2005), pp. 480 discussing that Indian courts have shown the propensity to address the issues of trade dress protection within the board parameters of the law on passing off.

Within the robotics industry, there are only a few examples of lawsuits asserting trade dress infringement claims based on the “look and feel” of a robot.[76] However, there are no known cases in which such a trade dress infringement claim has been decided on the merits.[77]

### 4.6 Copyright and robotics

The Copyright protection is relevant to robotics too, in several respects.

The best example of where robotics companies seek copyright protection is for software code that has been “reduced to writing” and is believed to be unique and original.[78] In practice, robotics companies typically use copyright enforcement to prevent others from copying, or simply accessing, their computer code.

It is generally accepted within most nations that circumventing an electronic barrier in order to gain access to copyrightable computer code is a violation of the 1996 WIPO Copyright Treaty.[79] This is particularly important to the robotics industry because most robotics companies employ electronic barriers to restrict access to their robot’s computer code. In the United States, the case law over the past several years also shows a trend suggesting that the United States, which is a signatory to the WIPO Copyright Treaty, will conform to the laws of most other nations and Article 11 of the WIPO Copyright Treaty, such that circumventing an electronic barrier in order to access copyrightable code – even if there is no act of copying giving rise to an independent claim for copyright infringement – would still constitute a violation of the United States’ Digital Millennium Copyright Act (DMCA) [80], which is the United States’ implementation of the WIPO Copyright Treaty.[81] The European Union has similarly taken measures to harmonize its laws with the WIPO Copyright Treaty by prohibiting the circumvention of electronic barriers in order to access protected copyrightable works. The EU has taken such steps by implementing Article 6 of European Directive 2001/29/EC.[82]

[76] See *e.g., iRobot Corporation v. Urus Industrial Corporation, et al.*, 1:05-cv-10914 (D. Mass. 2005) (lawsuit filed in the United States District Court for the District of Massachusetts by iRobot against Koolatron and Urus Indus. for alleged trade dress infringement, copyright infringement, and patent infringement); See *also, Innovation First, Inc., et al. v. Urban Trend, LLC, et al.*, 3:10-cv-934 (N.D. Tx. 2010) (lawsuit filed in the United States District Court for the Northern District of Texas by Innovation First against Urban Trend for alleged trade dress infringement, false designation of origin, false advertising, copyright infringement).

[77] See *e.g., iRobot Corporation v. Urus Industrial Corporation, et al.*, 1:05-cv-10914 (D. Mass. 2005) (lawsuit settled and consent judgment filed); See *also, Innovation First, Inc., et al. v. Urban Trend, LLC, et al.*, 3:10-cv-934 (N.D. Tx. 2010) (lawsuit settled).

[78] Another example of where copyright protection could be used for robotics, but is not necessarily a common practice in the industry is for a unique aesthetic design, such as a design pattern on a robot.

[79] See WIPO Copyright Treaty, Article 11 (1996) (prohibiting the circumvention of technological measures for the protection of copyrightable works).

[80] See Keisner (2012) citing *MDY Indus. LLC v. Blizzard Entertainment Inc.*, 629 F.3d 928 (9th Cir. 2010).

[81] See U.S. Senate Committee on the Judiciary, Report to the Senate on the Digital Millennium Copyright Act of 1998 (105 S. R.t. 105-190) (“Title I will implement the new World Intellectual Property Organization (WIPO) Copyright Treaty and the WIPO Performances and Phonograms Treaty, thereby bringing U.S. copyright law squarely into the digital age and setting a marker for other nations who must also implement these treaties”).

[82] See Directive 2001/29/EC of the European Parliament and of the Council of 22 May 2001, Official Journal of the European Communities, L 167/10, 22.6.2001.

Aside from disputes among companies, and despite the fact that some nations laws may provide for reverse engineering exceptions, copyright related anti-circumvention laws have also been invoked when an amateur scientist decrypts and changes software code. Although it was never the subject of a court decision, a company's assertion of a US Digital Millennium Copyright Act (DMCA) violation for the unauthorized accessing of the company's robot's software code is not new. When a consumer hobbyist decrypted the software code for Sony's robotic-dog, Aibo, and circulated the new software to other consumers such that they could "teach" the robotic-dog to dance and speak, among other things, the company asserted that such acts were a violation of the DMCA and demanded the removal of the software.[83]

### 4.7 What happens to inventions or creative works produced by robots, now and tomorrow?

A question that cannot yet be considered settled law in any nation, but for which IP practitioners around the globe may soon face, is whether IP can be created by a robot, and if so, who owns IP created by a robot?[84]

In the future, robots set to accomplish a task are likely to produce new solutions to problems and in so doing create physical or intangible products or outputs that could, at least in theory, be perceived as IP – new inventions, creative works or trademarks, for instance. This element of robotics innovation could raise interesting questions as to the set-up and boundaries of the current IP system. Are objects, software code or other assets created autonomously by a robot copyrightable or patentable? If so, how? And who would own these IP rights? The producer? The user of the robot? The robot itself?[85] Some countries such as Japan and the Republic of Korea are actually considering extending rights to machines.

Some case law is relevant too: For instance, it was recently determined by the US Copyright Office that a photographer did not own the copyright to a photograph that was taken by a monkey who temporarily "borrowed" his camera.[86] Given the ruling, some practitioners question whether photographs taken by robots would be protected by copyright.[87] Based on the language in the U.S. Copyright Office's recent Compendium, it appears that there would be no copyright protection in the United States for a work created by a robot.[88]

[83] See Mulligan & Perzanowski (2007) citing to multiple news sources and discussing Sony's assertion of a DMCA violation in stopping the use of unauthorized computer code distributed for use with its Aibo robotic-toy dog.

[84] Such "open" issues about robot-generated works and IP rights were the subject of Christophe Leroux's presentation at the November 2012 International Workshop on Autonomics and Legal Implications, see Leroux (2012).

[85] *Idem*.

[86] See Compendium of U.S. Copyright Office Practices, Third Edition (Public Draft – Not Final), August 19, 2014 clarifying that photographs taken by a monkey are not eligible for copyright protection; See *also* David McAfee, *Copyright Office Says It Will Not Register 'Monkey Selfie'*, Law 360, August 22, 2014.

[87] See Mark A. Fischer, *Are Copyrighted Works Only by and for Humans? The Copyright Planet of the Apes and Robots*, Duane Morris New Media and Entertainment Law Blog, August 18, 2014.

[88] *Idem.*

In the UK, on the other hand, there is dedicated legislation suggesting that copyright protection will be avoidable for robot-generated works.[89] Although it is debated how such legislation should be applied,[90] it is nonetheless an area of IP law applicable to robotics in which it appears that contradictory rules are emerging between nations with significant roles in the robotics industry.

In New Zealand, the law suggests that original works otherwise protectable if created by a human, are still eligible for copyright protection under New Zealand's Copyright Act of 1994 even if the work is instead created by software, robots or artificial intelligent systems.[91] Ownership of such works, however, would belong not to the robot or intelligent system, but instead to the person(s) who created or utilized the robot or intelligent system that ultimately created the work. In comparison, however, IP practitioners in Australia have noted, in light of some of the same case law referenced by New Zealand practitioners that the laws, while providing for copyright protection of computer generated works, still involve numerous aspects that make it practically difficult to assert copyright protection over a work generated by a computer, robot or intelligent system.[92]

A full legal assessment of this question relating to autonomous robot creation is beyond the scope of this report, but who owns the IP rights over creations produced by robots will surely be a matter of much future discussion.

## Conclusion

Few studies have analyzed the developments of robotics, the underlying innovation eco-system and the role of IP. This paper fills this gap by providing an up-to-date analysis of the robotics innovation system. Original patent landscape data are presented to shed light on robotics filing strategies and to identify top filers. The paper goes beyond the use of patents to also cover the role of trade secrets, industrial design, brands and copyright. To conclude the paper also shows how the emergence of robots could lead to new questions such as who owns the IP of works or inventions created by robots themselves?

[89] See RoboLaw, Guidelines Regulating Robotics, p. 19 (2014).

[90] *Idem.*

[91] See Simpson Grierson, Earl Gray, Raymond Scott, *If Shakespeare were a robot, would "he" be an "author"?*, lexology.com, February 28, 2011 discussing New Zealand's Copyright Act and recent decisions by the Australian Federal Court suggesting that original works are copyright protected in New Zealand.

[92] See Tim Clark, Ivor Kovacic, *Copyright in works generated by computer programs*, Lexology.com, August 31, 2011.

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## Technical Annex

Part of the empirical analysis of this paper relies on a tailor made patent mapping. The patent data for these mappings come from the WIPO Statistics Database and the EPO Worldwide Patent Statistical Database (PATSTAT, April 2015).

The patent mapping strategy was adapted from the seminal work by the UKIPO[93] combining CPC and IPC symbols with text terms searched for in titles and abstracts. In particular, we have included the following list of IPC and CPC symbols: B25J 9/16, B25J 9/20, B25J 9/0003, B25J 11/0005, B25J 11/0015, B60W 30, B60W2030, Y10S 901, G05D 1/0088, G05D 1/02, G05D 1/03, G05D2201/0207, and G05D 2201/0212; complemented with the following terms: *robot*, *robotics*, and *robotic*.

The resulting sample was benchmarked against a list of seminal patents and a list of robotics companies. The latter was compiled – along with their geographic locations and the company type –based on information about robotics companies available to robotics-focused associations and groups, including The Robot Report's Global Map, as well as from the publicly available listing of companies from the Robotics Industry Association (RIA). While these sources are useful to corroborate the location of robotics companies, and the formation of robotics clusters, which supports the perceived importance of collaboration within the industry, the identification of robotics companies by such robotics-focused associations and groups has certain shortcomings in the way that they are used herein. Nonetheless, it appears that the shortcomings are minor and do not have a significant impact on the conclusions derived from the data (see **Figure 2** and footnote 29).

The main unit of analysis is the first filing of a given invention.[94] In consequence, the date of reference for patent counts is the date of first filing. The only departure from this approach occurs when analyzing the share of patent families requesting protection in each patent office in figure **Figure 7**. In this case, an extended patent family definition – known as the INPADOC patent family – has been used instead of the one relying on first filings. In addition, only patent families with at least one granted application have been considered for this analysis, and the date of reference is the earliest filing within the same extended family. The main rationale for using the extended patent family definition and imposing at least one granted patent within the family is to mitigate any underestimation issuing from complex subsequent filing structures, such as continuations and divisionals, and from small patent families of lower quality such as those filed in only one country and either rejected or withdrawn before examination.

The origin of the invention is attributed to the first applicant of the first filing; whenever this information was missing an imputation strategy has been applied. When information about the first applicant's country of residence in the first filing was missing, the following sequence was adopted: (i) extract country information from the applicant's address; (ii) extract country information from the applicant's name (see further below); (iii) make use of the information from matched corporations (as described further below); (iv) rely on the most frequent first applicant's country of residence within the same patent family (using the extended patent family definition); (v) rely on the most frequent first inventor's country of residence within the same patent family (again, using the extended patent family definition); and (vi) for some remaining historical records, consider the IP office of first filing as a proxy for origin.

Applicants have been categorized in three broad categories: (a) *Companies*, which includes mostly private companies and corporations, but also state-owned companies; (b) *Academia*

[93] See UKIPO (2014).

[94] Mappings include data on utility models whenever available.

*and public sector*, which includes public and private universities (and their trustees and board of regents), public research organizations, and other government institutions such as ministries, state departments and related entities; (c) *Individuals*, which includes individual first applicants who may or not be affiliated with companies, academia or other entities. A further category, (d) *Not available*, includes all unclassified first applicants.

In order to assign broad type categories to each first applicant, a series of automated steps were performed for each of the six innovation fields underlying the case studies, to clean and harmonize applicant names. The results of this automated process were cross-checked manually – particularly for the top applicants of each type – prompting revision of the strategy and adjustment of parameters in several iterations.

The starting point was the original information about the first applicant's name from the first filing. When this name was missing, the most frequent first applicant's name within the same patent family using the extended definition was considered. This list of improved first applicants' names was automatically parsed in several iterations in order to: (i) harmonize case; (ii) remove symbols and other redundant information (such as stop words and acronyms); (iii) remove geographical references (used to improve information on applicants' country of residence); and (iv) obtain any valuable information on applicant names meeting criteria to be considered as (a) *companies* or (b) *academia and public sector* types.

Subsequently, a fuzzy string search was performed – using Stata's *matchit* command[95] – in order to detect alternative spellings and misspellings in applicant names, and the types were propagated accordingly. In addition, the results of corporation consolidation (see below) also permitted recovery of some unclassified applicant names as *companies*. Finally, the category *individuals* was imputed only to remaining unclassified records when they either appeared as inventors in the same patent or were flagged as individuals in the WIPO Statistics Database for patent families containing a PCT application. Analysis of the unclassified records indicates that most of them have missing applicant names in PATSTAT. Most of these missing names refer to original patent documents not in Latin characters and without subsequent patent filings.

The rankings provided for robotics consolidate the patent filings of different first applicants. Manual examination and consolidation was performed for the most frequent applicants. Applicants sharing a common ultimate owner were consolidated into one. In the case of the top 30 companies, the ownership profiles in the *BvD Ownership Database* were used. Only subsidiaries that were directly or indirectly majority owned were taken into account in the consolidation.

[95] Available at the Statistical Software Components (SSC) archive and from the WIPO website.