CENTER FOR THE GOVERNANCE OF CHANGE

A STUDY OF THE STATE OF DIGITAL HEALTH INNOVATION TRENDS IN THE EU

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Innovation, Sustainability, and the Future of Healthcare
Chapter 2

Europe is facing the **rising challenge** of an ageing population and changing disease patterns. In addition, the *care* workforce is insufficient (a lack of staff in social care can have direct effects on the quality of healthcare). **Digital health innovations** and, in particular, artificial intelligence (AI) technologies, Big Data and the Internet of Things (IoT) have the potential to alleviate some of these strains. This realization has led to the appearance of a plethora of digital health companies and devices, as well as initiatives and policies to incentivize their development and implementation.

The novelty and **rapid pace** of technological development in the digital arena has so far made it difficult to analyse and rationalize its growth and composition patterns across European countries. To overcome this gap we have mined the **worldwide patent database**, identifying countries that are leading in digital health innovation and gaining insights on the particular areas that are being favoured.

The data shows that most of the innovation is driven by just a few European countries, led by Germany, the Netherlands, France and the United Kingdom. **Big data analytics** is still the dominant area across biotechnological and pharmaceutical applications, but in MedTech, **artificial intelligence applications** have also grown significantly. Countries leading in digital health innovation have developed policies and initiatives to support and encourage it, while preparing for its risks.

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1. MAPPING TECHNOLOGICAL INVENTIONS IN THE DIGITAL HEALTH SECTOR

We have mapped and tracked the development of digital health innovation in Europe using patent data indicators. Patent data has the advantage of allowing large-scale quantitative assessments of technological development. Patents confer temporary monopolies to developers of new inventions that have an industrial application and represent a non-obvious inventive step in comparison with prior art. This makes patent data a valuable source of information to study technological development. In addition, patents leave an open paper trail of forward and backward citations, as inventors have to acknowledge relevant prior art to their inventions. This trail allows for the tracing of the origin of new technologies and where these technologies were further built upon.

The drawbacks of using patent data are well known. Using patent data to measure innovation restricts the analysis to assessing the technological dimension of innovation. It therefore excludes other types of innovation, such as new business models or marketing strategies, which are critical for the successful commercialization of new products and services. Moreover, not all technological inventions are patented, as firms can often choose other exclusionary strategies, such as keeping trade secrets. However, research in economics of science and technology indicates that patent data contains granular information that can give a good indication of economic value. For example, the number of times a patent is cited (forward citations) is strongly associated with social impact [1] and private value [2], [3].

In this study we will first examine the trend in the quantity of the patents filed in the PATSTAT database, the worldwide patent statistical database. We will then scrutinize the respective sectors to understand how the different countries relate to each other in the adoption of big data analytics, AI and the IoT in the patents filed in biotechnologies, medical technologies (Medtech) and pharmaceuticals. Finally, we will highlight some of the policies in the top four countries that, according to our analysis, are leading the way in research and innovation in health and healthcare.

Disaggregation per digital health technological sub-classes

We have identified digital health innovations by searching for patents which belonged to both a health category—biotechnology, medical technology (MedTech) and pharmaceuticals—and an information technology (ICT) category. There are thirteen such ICT categories, which we further classify into big data, AI and IoT technologies.Further details concerning these patent classifications can be found in the Appendix.

Big data analytics in health. The increasing availability of health data is enabling radically new forms of treatment and diagnostics. Policymakers are seeking to combine varied sources of health data to enable comparative effectiveness research (CER). Combining personal health data across the public and private sectors contributes, for example, to leaps in evidence base for clinical care, monitoring quality and aiding the discovery of biomarkers for the development of better diagnostics and drugs.

An increasingly prominent application of big data analytics in health is the development of precision medicine or the personalized medicine sector. Precision medicine includes, for example, medical treatments, practices and drugs tailored to the specific characteristics of individual patients. Patients' risk profiles are created based on the analysis of genetic information and clinical information, which requires data linking and large-scale genomic databases. Examples of policy initiatives promoting the exploration of combined health data include the German Centre of Health Research initiative which funds platforms for precision medicine at the German Consortium for Translational Cancer, and established a genome sequencing platform. In Australia, the National Health and Medical Research Council (NHMRC) provides funding for data-driven healthcare through its Medical Research Future Fund [4].

Artificial intelligence in health. Remarkable progress has recently been made in the application of AI to digital health. A prominent example is drug design. A key step in drug design is learning about quantitative-structure activity relationships (QSARs), which particularly benefit from machine learning techniques. The standard QSAR learning problem is "given a target (usually a protein) and a set of chemical compounds (small molecules) with associated bioactivities (e.g. inhibition of the target), [and] learn a predictive mapping from molecular representation to activity" [5]. AI is increasingly being combined with laboratory robotics in drug design stages to automate research activities. In 2018, the United Kingdom announced a new facility at the Rosalind Franklin Institute, which is transforming the UK pharmaceutical industry by fully automating molecular discovery to produce new drugs up to ten times faster [6].

AI applications are also being deployed to tackle rare diseases more effectively as well as diseases affecting disproportionately less developed countries. For example, in 2015, the pharmaceutical company Atomwise initiated a partnership with researchers at the University of Toronto and IBM to use AI technology in performing Ebola treatment research. In this collaboration, Atomwise provided the core AI technology to perform drug research and researchers from the University of Toronto contributed biological insights about the Ebola virus while IBM supplied the supercomputer for the analysis [7].

One of the more accessible ways that healthcare users experience AI in their healthcare systems is through the utilization of symptom checkers that act as a substitute for doctor visits. Some examples in the United Kingdom include Ada, Your.MD and Babylon. These can help reduce the burden on healthcare professionals, offering precise and earlier diagnosis that could lead to more diseases being prevented.

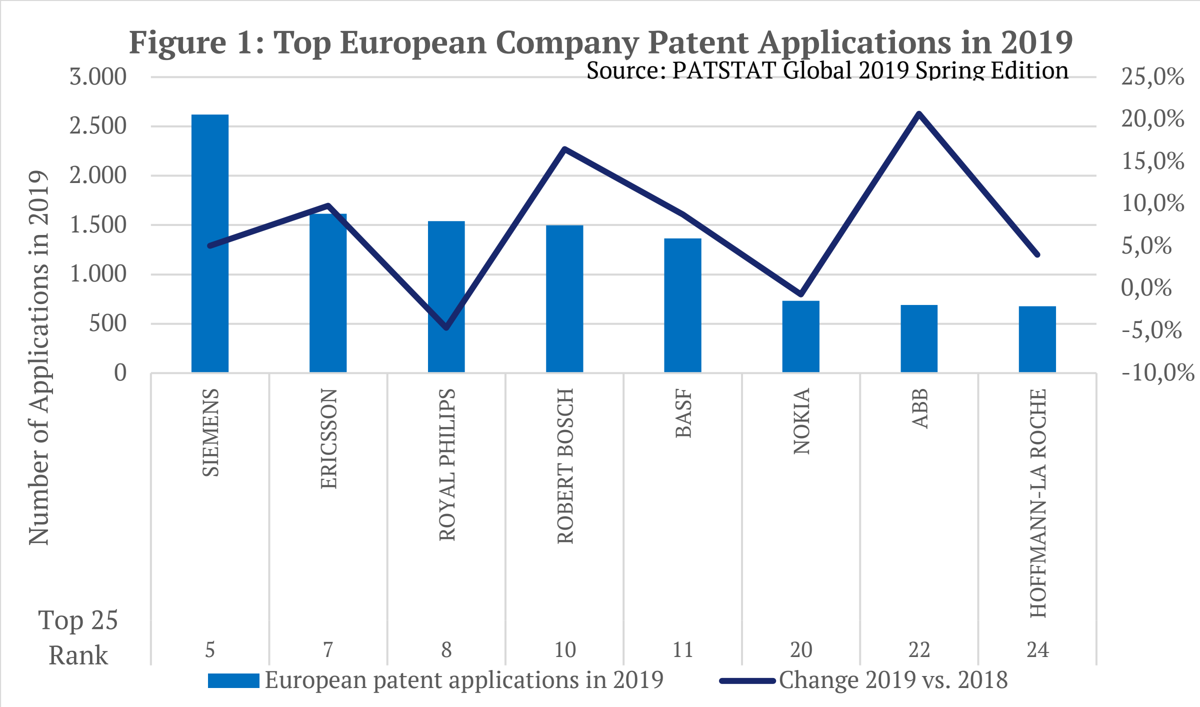
Internet of Things in health. Internet of Things technologies can have a major impact on human lives and health with the spread of health sensors and health robots. For example, doctors can now perform so-called capsule endoscopies using a pill-shaped micro-camera with wireless data communication capabilities that travels through a patient's digestive system and transmits images to a computer. Moreover, physicians and nurses can have access to patient data based on wearable technology and hospital sensors being able to monitor health conditions and predict different needs in real-time. For example, the AutoBed platform monitors up to 1200 beds and processes 80 bed requests at a time, keeping track of patient requirements like nurse proximity. In 2013, New York's Mt. Sinai Hospital (United States) installed the AutoBed system and sensors to connect and track hospital beds. As a result, hospital staff knew exactly when and where a bed was free, which reduced emergency room wait times by several hours for half the hospital's patients [8]. An additional example is the monitoring of real-time patient data via wireless radio frequency identification (RFID). This platform gives providers a way to easily monitor patients in a more personalized form. In 2018, the Missouri Delta Medical Centre in Sikeston (United States) deployed such a platform for wireless monitoring of temperature and humidity conditions throughout the hospital, including in refrigerators, freezers, incubators and procedure rooms [9].

Robotic surgeries are another example of how the IoT is being used for minimally invasive procedures. With increasing levels of connectivity and integration between data analytics and hardware, AI-assisted robotic surgery is now possible. For example, in 2017, the Maastricht University Medical Centre (Netherlands) used an AI-assisted surgery robot to suture small blood vessels no larger than 0.03 millimetres and up to 0.08 millimetres across. The robotic system is controlled by a surgeon whose hand movements are converted into smaller, more precise actions that are performed by a set of robotic "hands". The system uses AI to stabilize any tremors in the surgeon's movements, to ensure the robot performs the procedure as smoothly as possible [10]. While AI-assisted robotic surgery is still in its infancy, it is progressing rapidly as health systems collect and integrate more and more data into their processes.

2. RECENT DEVELOPMENTS IN DIGITAL HEALTH TECHNOLOGICAL DEVELOPMENT – 2019 DATA

In this section, the 2019 data is presented to give an idea of the direction of the innovation in the years since 2014 to 2019, the latest year for which PATSTAT data is available.

Of the top 25 applicants in 2019, 8 companies originated from Europe. The top European company was Siemens, based in Germany, coming in 5th with 2019 European patent applications that year, exhibiting 5.1% growth over patents filed in 2018. There were two other German companies in the top 25, coming 10th and 11th respectively. Other top European filers were companies from Sweden, the Netherlands, Finland and Switzerland.



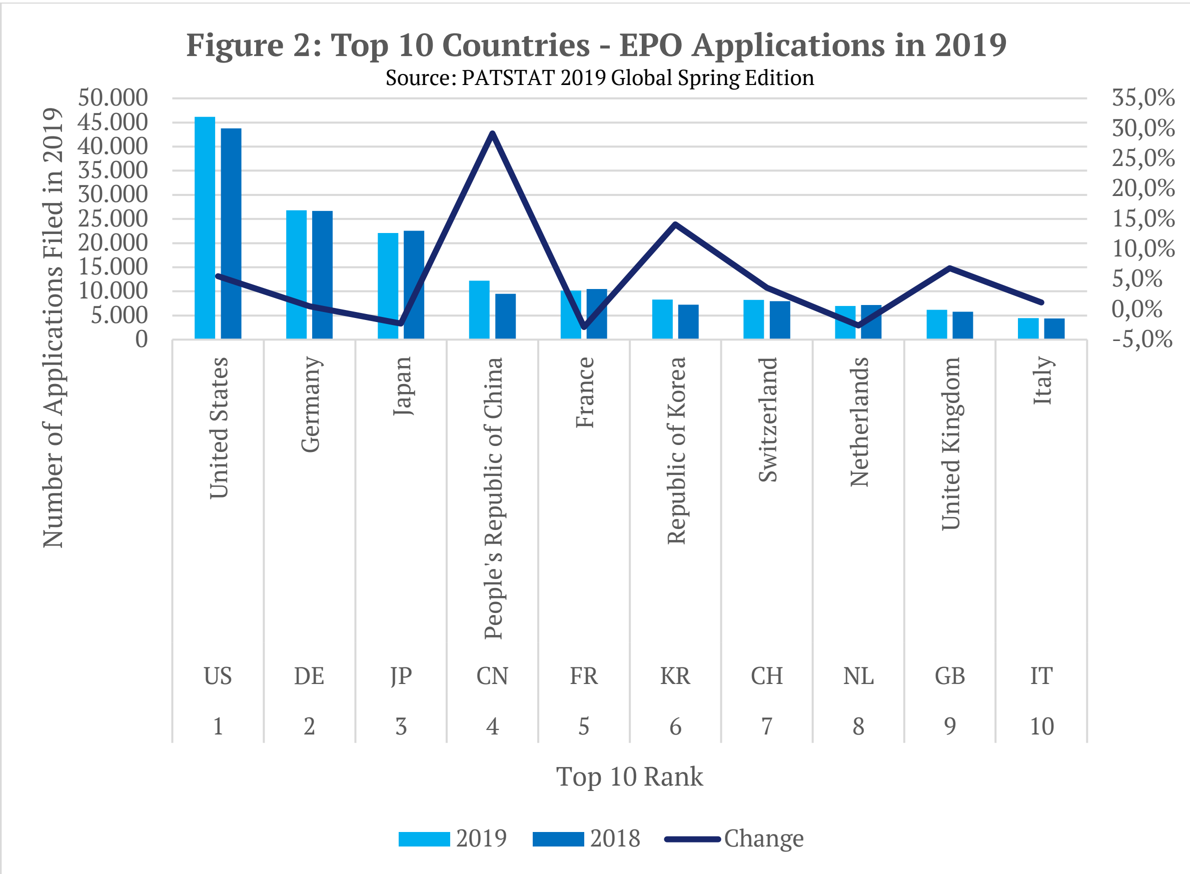


Figure 2 shows the top 10 countries filing patents at the European Patent Office (EPO) in 2019. Germany was the first European country, with France, Switzerland, the Netherlands, United Kingdom and Italy also in the top 10 in 2019.

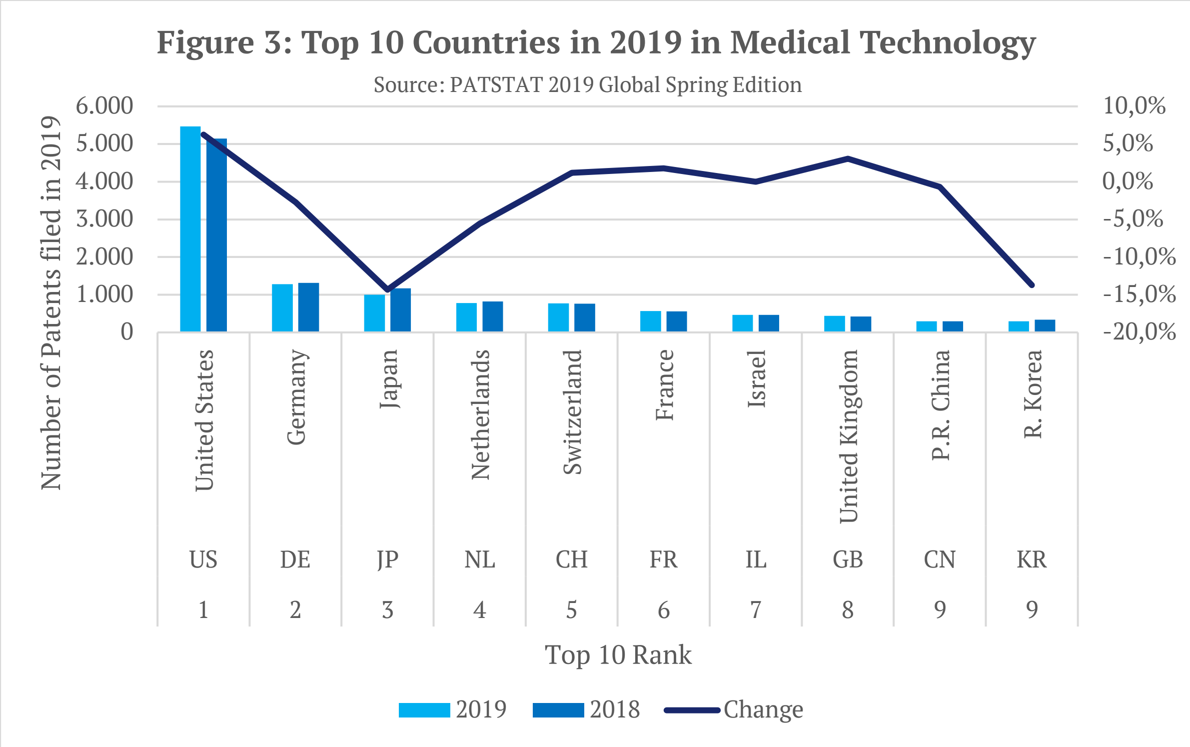


Figure 3 gives an indication of the trends in patent activity in biotechnology for the year 2019. Of the top 10 countries filing patents in biotechnology, 6 were European countries, with Germany leading the way and followed by France, Switzerland, the Netherlands, United Kingdom and Denmark. Comparing this data with that of 2018, Germany, Switzerland, the Netherlands and Denmark had more patents filed in biotechnology in 2018 than in 2019. The converse is true for France and the United Kingdom, who had more patents filed in biotechnology in 2019 than in 2018.

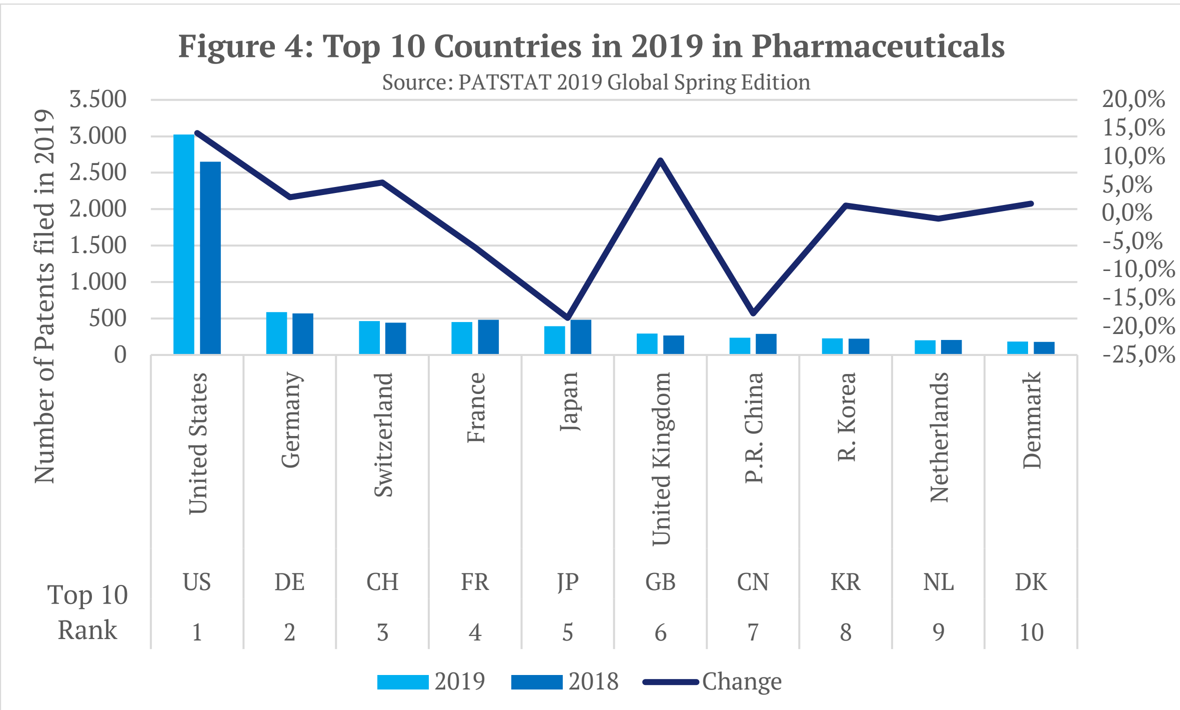


Figure 4 gives an indication of the top 10 countries that filed patents in pharmaceuticals for the year 2019. Of these countries, Germany was the leading European country, followed by Switzerland, France, the United Kingdom, the Netherlands and Denmark. Comparing data between 2018 and 2019, Germany, Switzerland, the United Kingdom and Denmark had an increase of patents filed in 2019 from 2018, while the Netherlands had a small decline of 2 patents less in 2019.

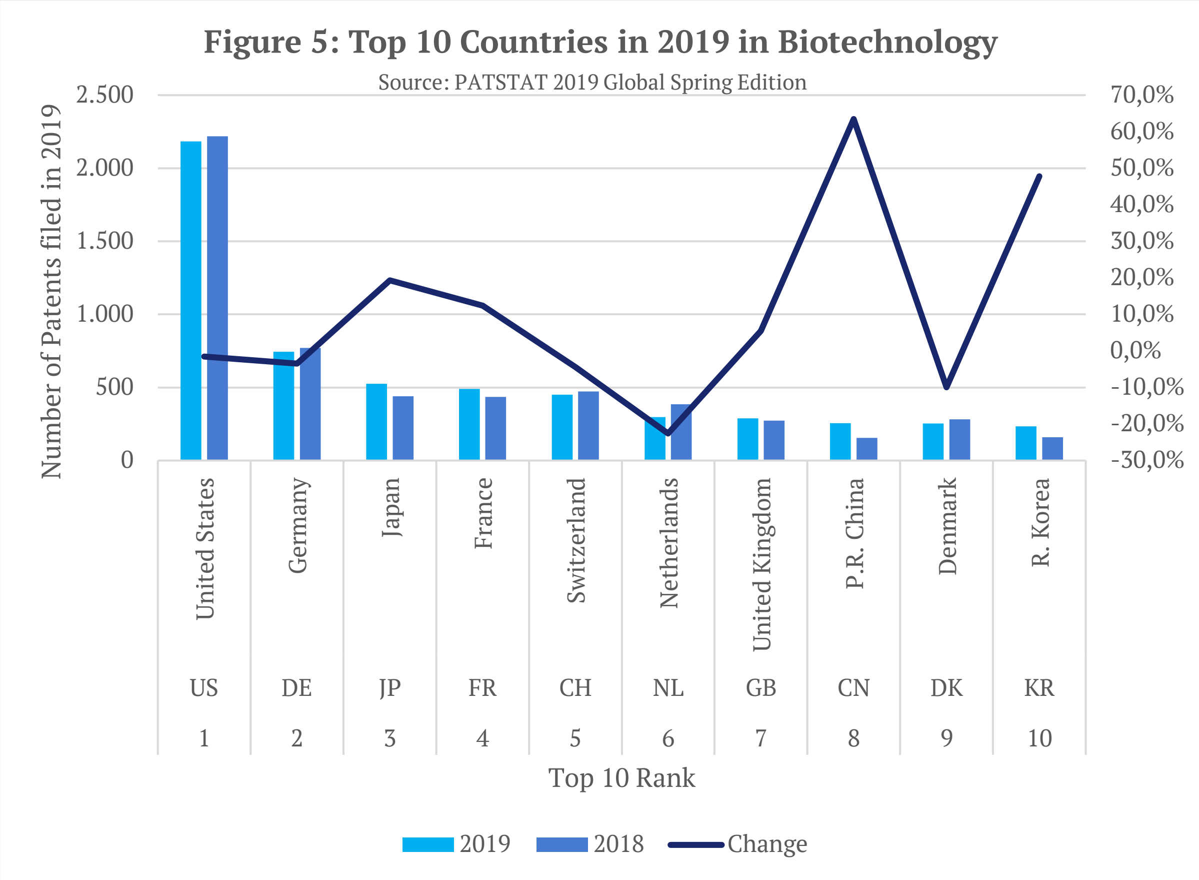


Figure 5 shows the top 10 countries that filed patents in medical technology in 2019. Of these, Germany was second with the Netherlands, Switzerland, France and the United Kingdom representing Europe in the top 10. Comparing data between 2018 and 2019, Switzerland, France and the United Kingdom increased the patents filed in medical technology, while Germany and the Netherlands had a decline.

This section on the trend in patent filing between 2018 to 2019 demonstrates the top filing countries in Europe in the three different sectors: biotechnology, pharmaceuticals and medical technologies. Germany filed the most patents in each sector; other top filers were France, Switzerland, the United Kingdom and the Netherlands.

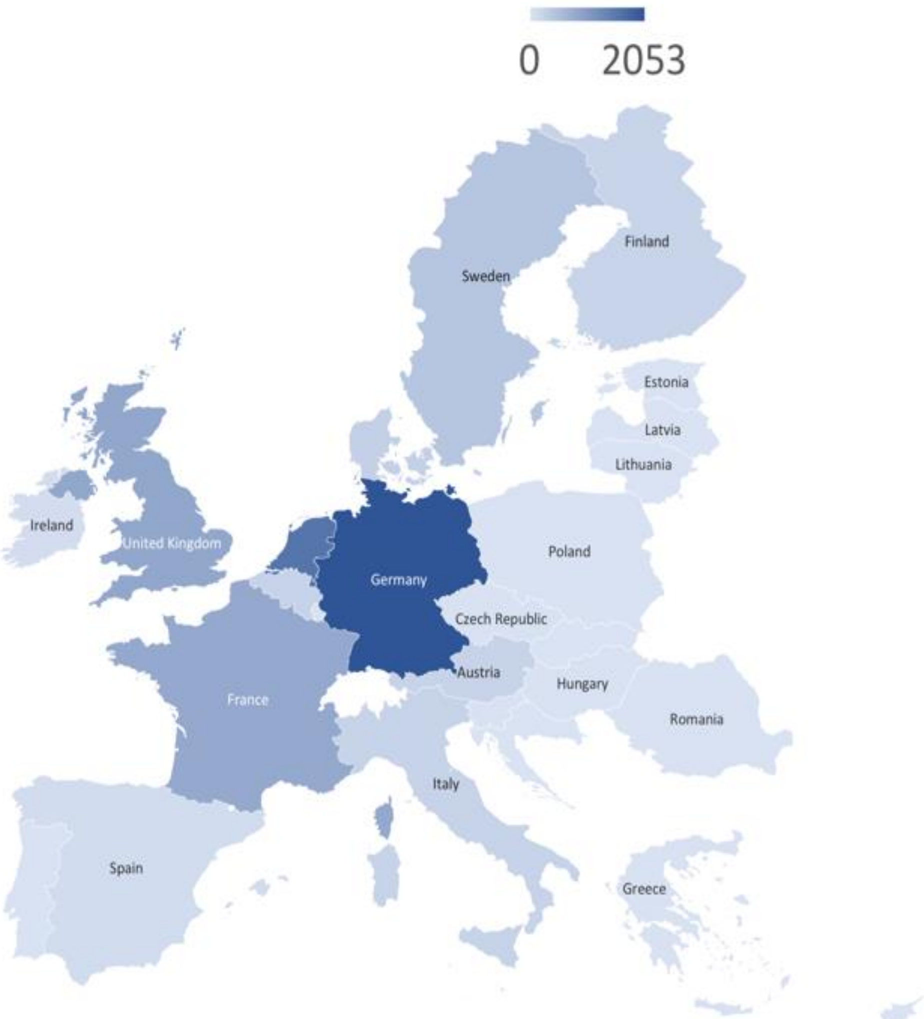
The above figures give an indication of the emerging leaders in the patents filed in these areas in 2019. The report now moves into the main analysis, where data is limited to 2014 for completeness, to analyse the actual complete patent activity in these countries during this period.

3. OVERVIEW OF EUROPEAN DIGITAL HEALTH TECHNOLOGICAL DEVELOPMENT

In this section we present the number of patent applications in digital health sectors across time and countries. We restrict our analysis to patent applications to the European Patent Office (EPO) filed by members of the European Union in the stated time period, 1990–2014. We restrict the data to 2014 as the data for the years following is still incomplete due to the amount of time it takes for the process to be completed, which may result in an under-reporting of the actual patent activity.

Figure 6: Total Number of Patents in Health in the EU: 1990-2014

Source: PATSAT Global 2019 Spring Database



Figures 6–8 are indicative of the direction of patent activity from 1990 to 2014. We have divided the data into three tiers: the first includes the economies that filed below 25 patents, as seen in Figure 7. In this group, some economies, notably Cyprus and eastern European economies including Estonia and Lithuania, filed just 1 patent in this 24-year period.

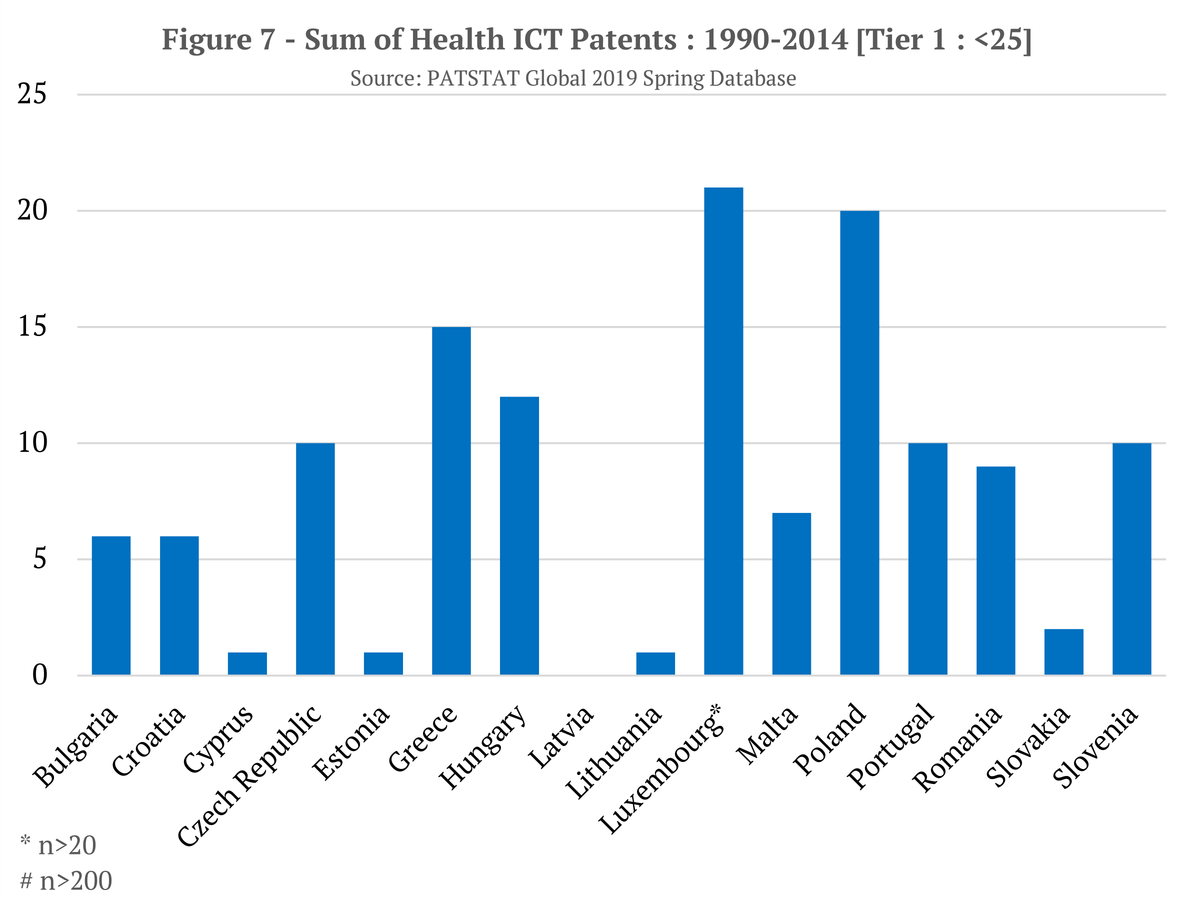


Figure 7 - Sum of Health ICT Patents : 1990-2014 [Tier 1 : <25]
Source: PATSTAT Global 2019 Spring Database
25
20
15
10
5
0
Bulgaria
Croatia
Cyprus
Czech Republic
Estonia
Greece
Hungary
Latvia
Lithuania
Luxembourg*
Malta
Poland
Portugal
Romania
Slovakia
Slovenia
* n>20
# n>200

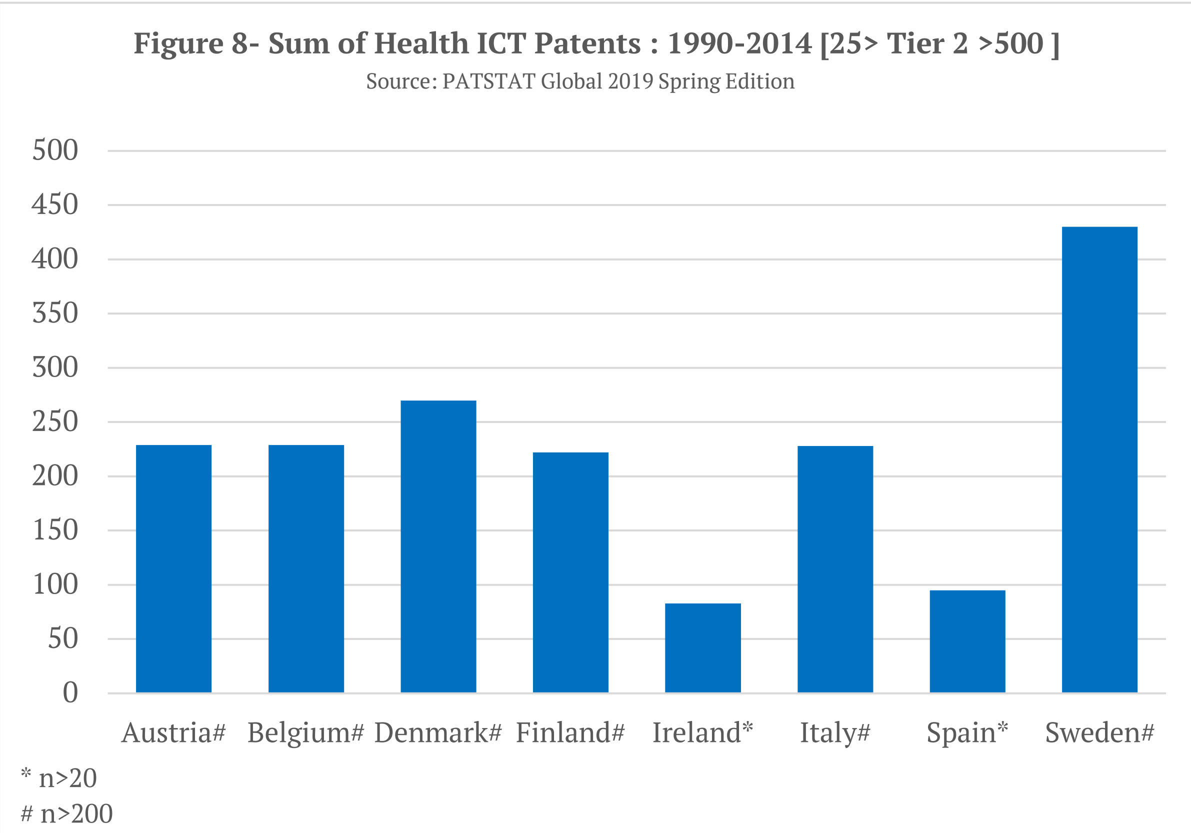
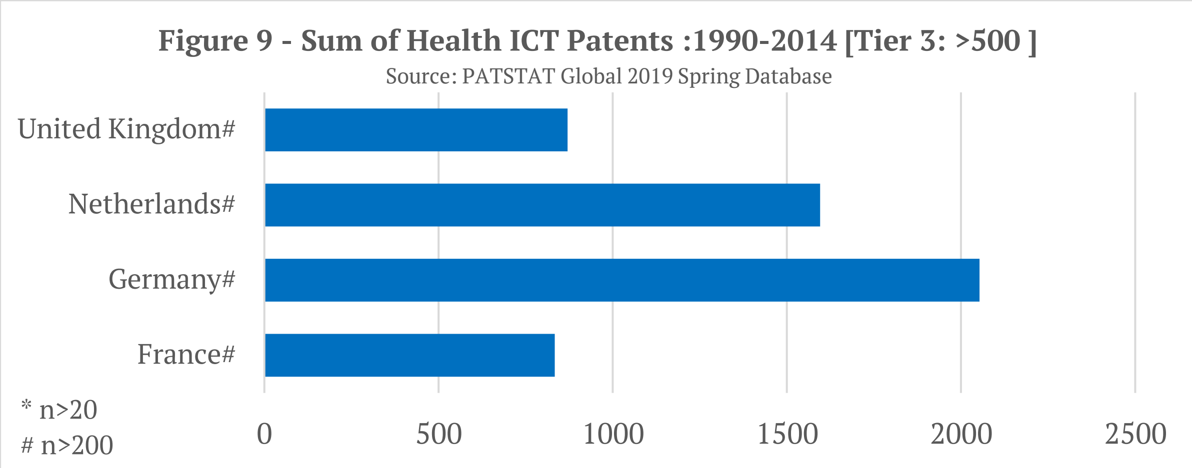


Figure 8- Sum of Health ICT Patents : 1990-2014 [25> Tier 2 >500]
Source: PATSTAT Global 2019 Spring Edition
500
450
400
350
300
250
200
150
100
50
0
Austria#
Belgium#
Denmark#
Finland#
Ireland*
Italy#
Spain*
Sweden#
* n>20
# n>200

In the second tier, shown in Figure 8, we see the economies that filed patents ranging from 83 patents to430 patents. The leader here is Sweden, which filed 37% more patents than the next highest filer: Denmark.



In the third tier, shown in Figure 9, we have the economies that led in patent filing during this period. We can group these economies into two groups: those filing below a thousand (France and the United Kingdom); those filing more than 50% more (the Netherlands and Germany). Figure 10 addresses the differences between how these countries lead in the three categories (big data analytics, artificial intelligence and the Internet of Things), indicating either synergies between the categories or if different economies are leaders in specific categories.

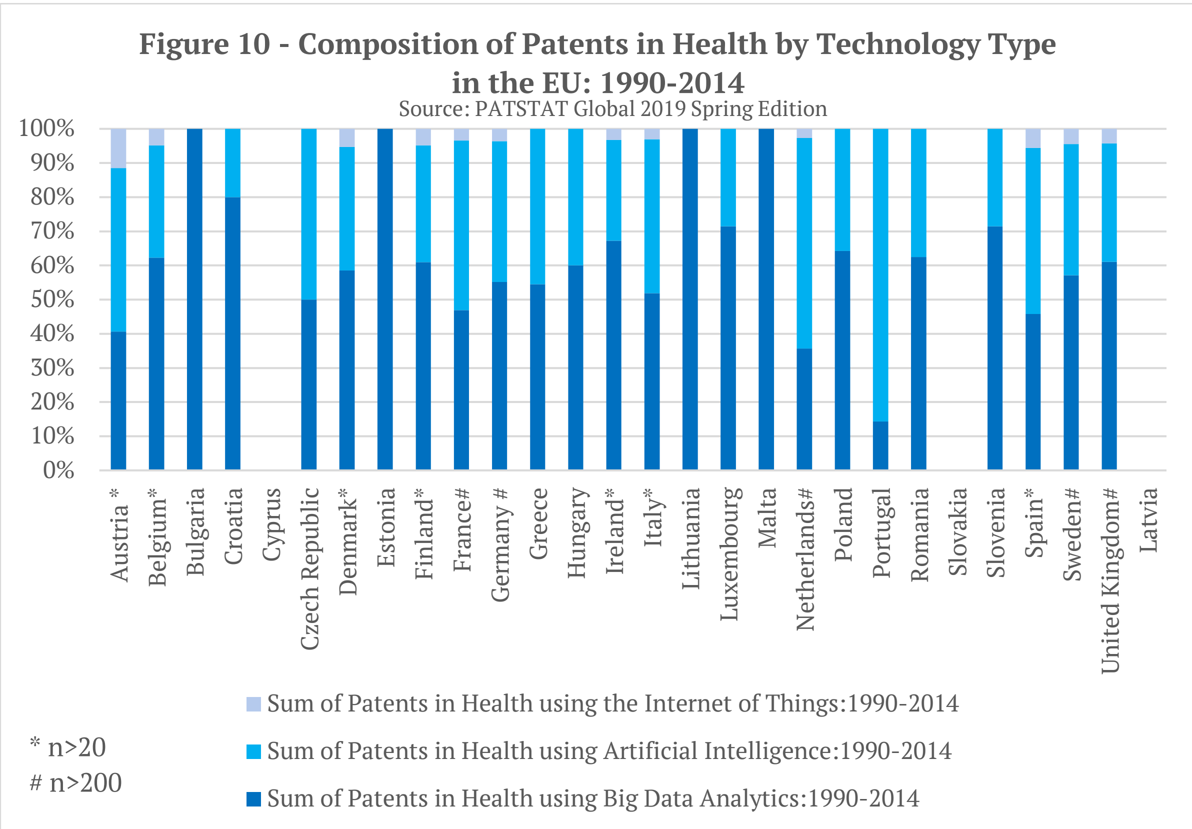


Figure 10 shows the different countries, indicating the composition of patents filed across the IoT, AI and big data analytics. In this grouping, France, Germany, the Netherlands, Sweden and the United Kingdom are the top filers, and Cyprus and Slovakia have no patents filed in these categories. The Netherlands filed 999 patents and Germany filed 1259 patents in these categories. It is interesting to see that the top filers in these three categories file all three types of patents, with the IoT always being the least represented. In Germany, the dominant type of patent is in big data analytics, while in the Netherlands AI dominates. A similar trend is clear in France, Sweden and the United Kingdom, with a minority of patents for IoT. The spread between big data analytics and AI is more equal in France and Sweden, but in the United Kingdom big data analytics takes dominance.

Figure 11 - Composition of Patents in Health in the EU by Digital ICT Breakdown: 1990-2014

Source: PATSTAT Global 2019 Spring Edition

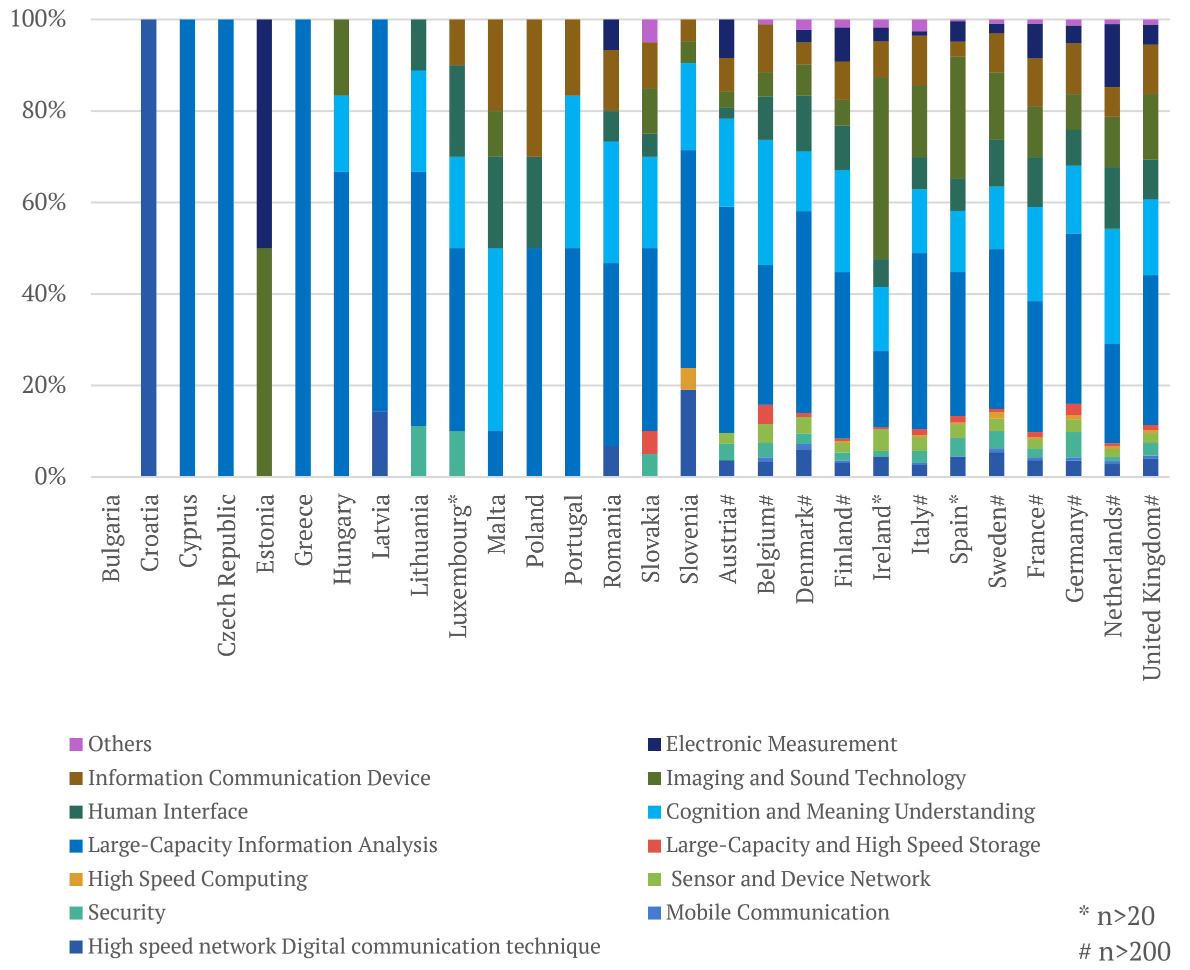


Figure 11 is insightful in giving an overall picture of the trends in the different countries in terms of the types of technologies that these patents centre on. These classifications represent the full spectrum of the types of digital ICT technologies for patents in health; analysis of all these classifications is beyond the scope of this analysis. Figure 11 captures nicely the diversity in the types of technologies.

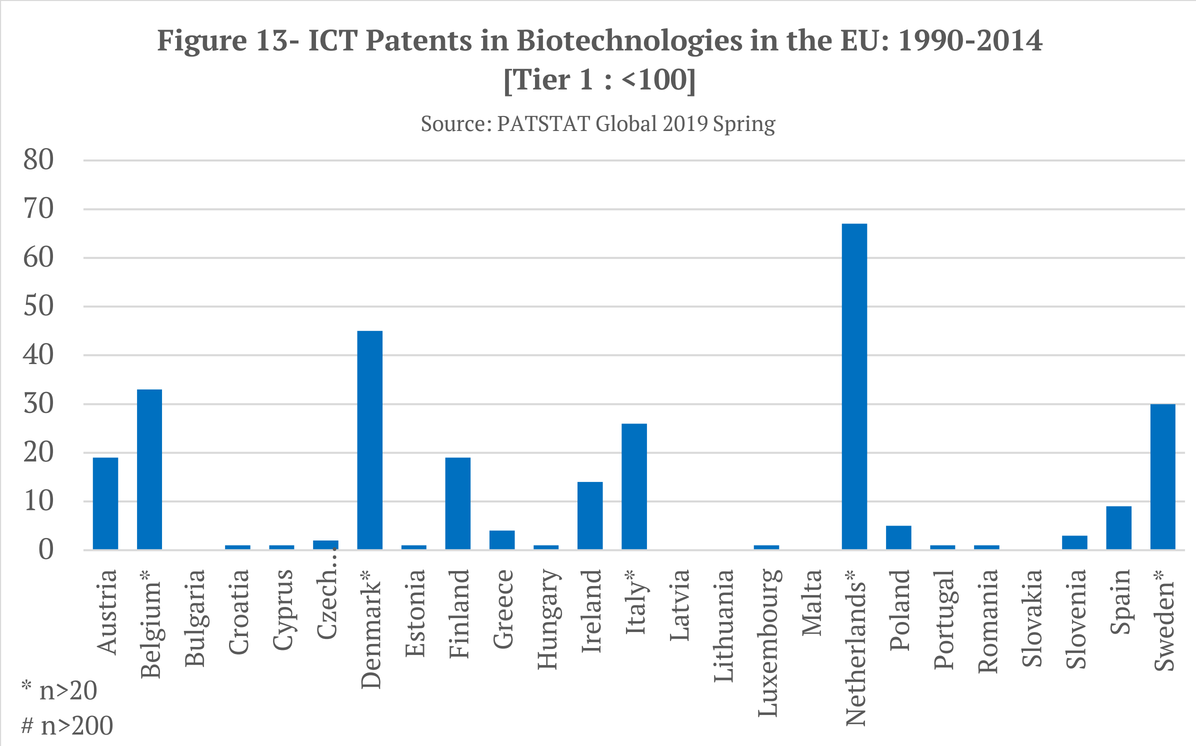
4. THE DIGITAL HEALTH PATENT LANDSCAPE: BIOTECHNOLOGIES, PHARMACEUTICALS AND MEDTECH

Biotechnology

In this section, we focus on patents filed in biotechnologies using digital technologies. Figures 12 and 13 show that the top two filers were the Netherlands with 67 patents and Denmark with 45 patents. For the Netherlands, these patents in biotechnologies constituted 4% of the overall patents filed in health using digital technologies. For Denmark, however, the patents in biotechnologies constituted 16% of all the patents filed in health using digital technologies over this period.

Figure 12: Total Number of Patents in Biotechnologies in the EU: 1990-2014

Source: PATSAT Global 2019 Spring Database



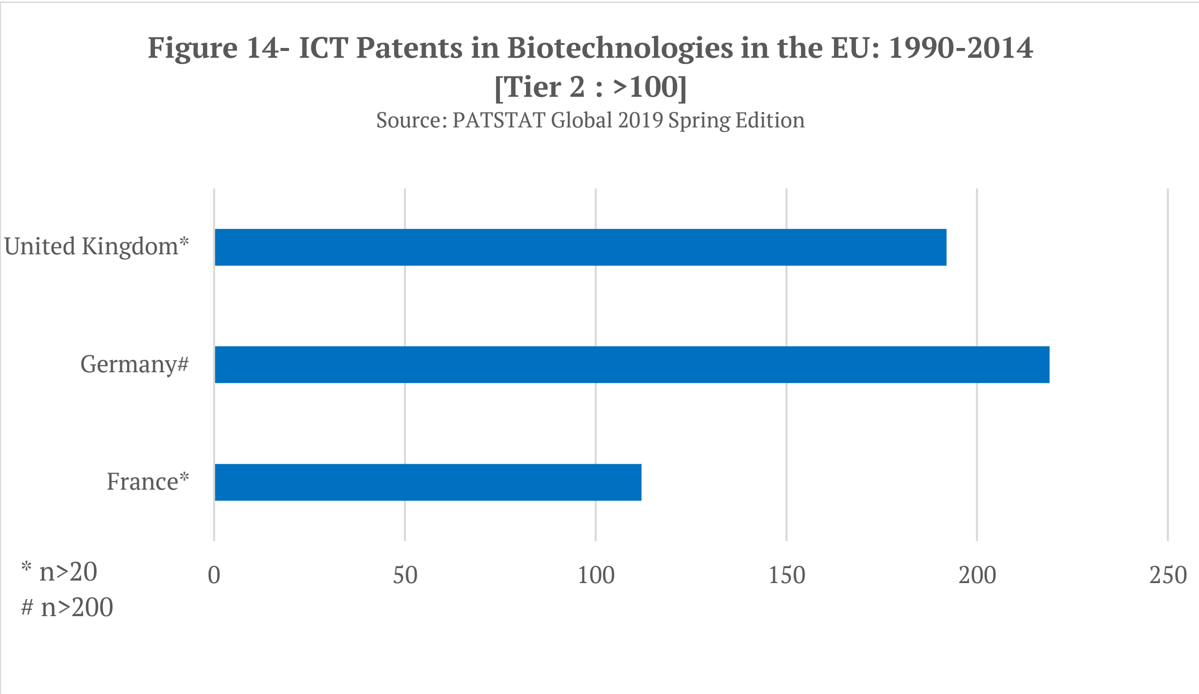
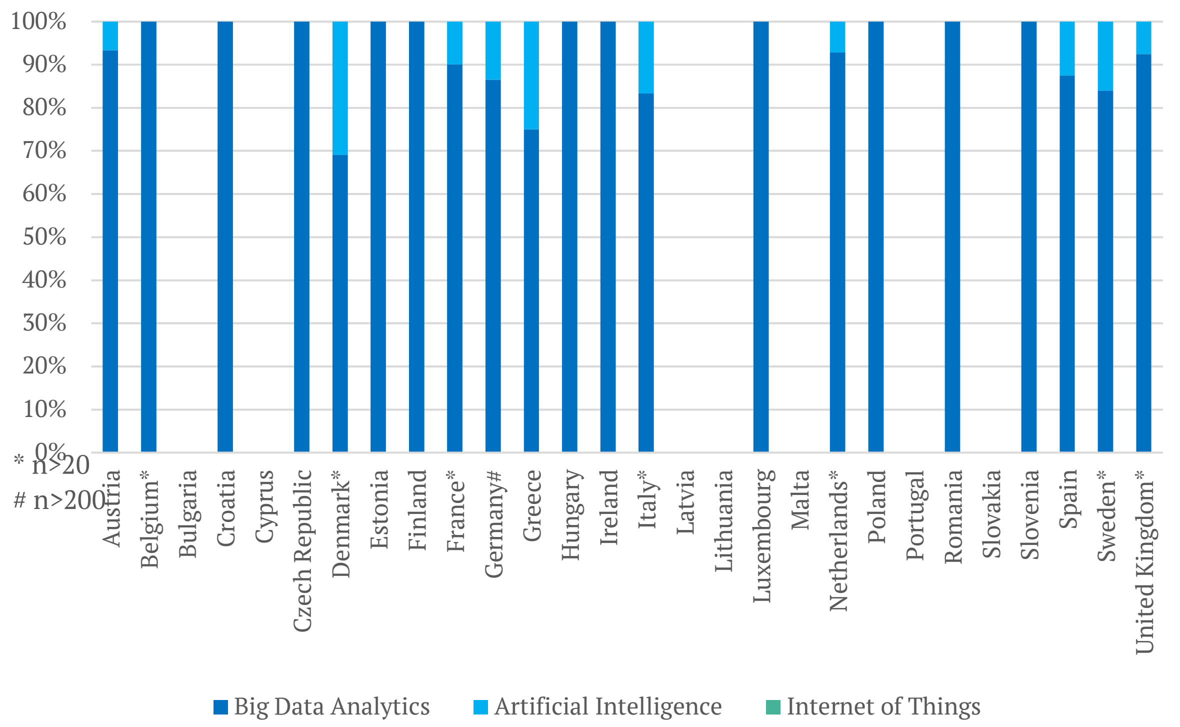


Figure 14 shows the second tier, with economies that filed above 100 patents in biotechnologies during this period. For France, the 112 patents constituted 13% of the total patents in health using digital technologies, while for Germany the 219 patents constituted 10% of the total. For the United Kingdom, the 192 patents constituted 22% of the total.

Figure 15 - Composition of Patents in Biotechnologies by Technology Type in the EU: 1990-2014

Source: PATSTAT Global 2019 Spring Edition



Research in this area is important to life expectancy and the quality of life. Biotechnology forms the foundation for the majority of modern medicine. When we examine the composition of biotechnology patents filed by European countries in the three digital technologies that this analysis focuses on, it is clear from Figure 15 that the IoT does not feature. While the overall mean of patents filed by all these economies is 22.7, with a standard deviation of 54.9, the bulk of the biotechnology patents were in big data analytics with a mean of 16.8, with a standard deviation of 39.5. In comparison, biotechnology patents in AI had a mean of 2.2, with a standard deviation of 5.52.

Figure 16 - Composition of Patents in Biotechnologies in the EU by Digital ICT Breakdown: 1990-2014

Source: PATSTAT Global 2019 Spring Edition

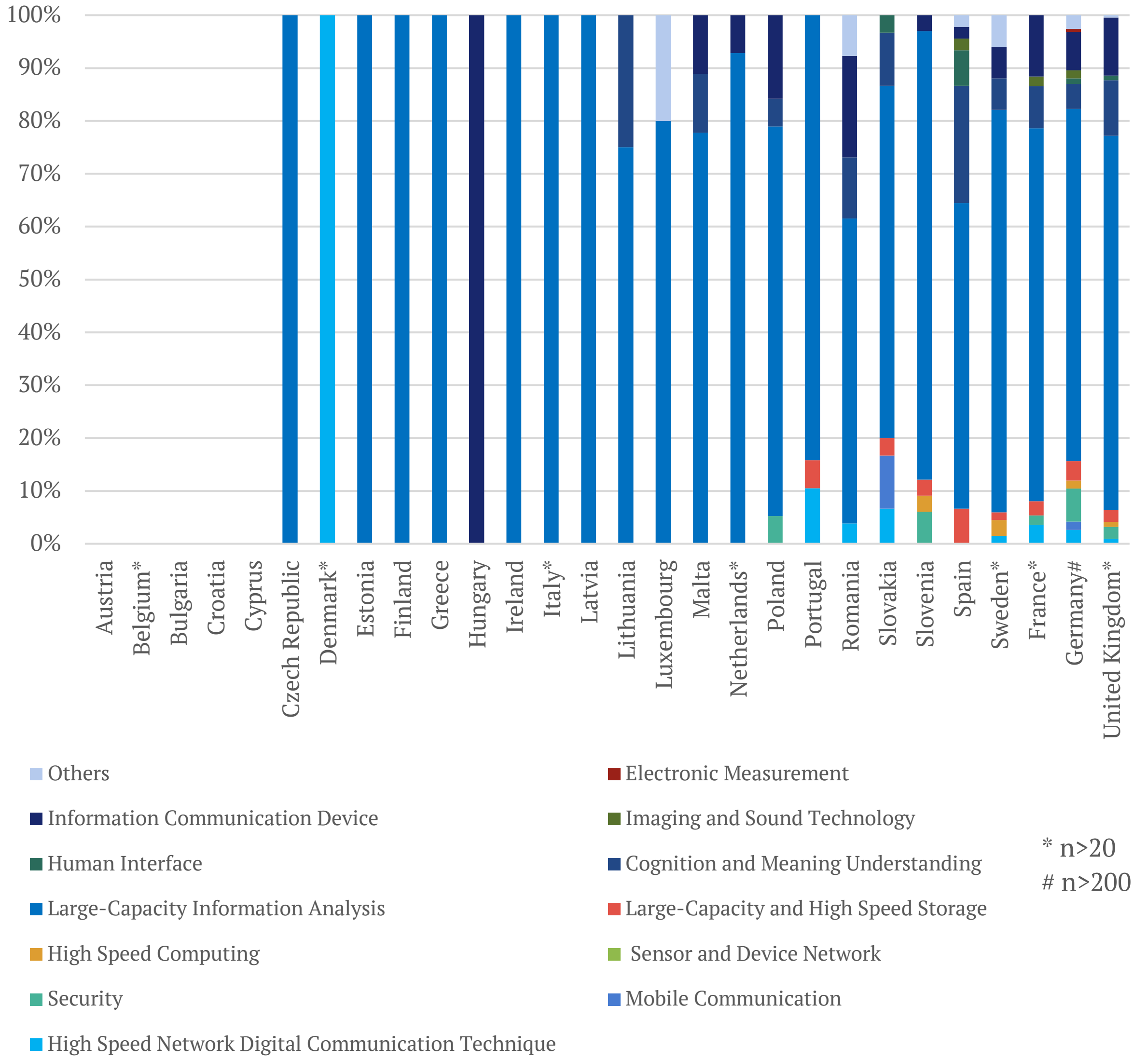


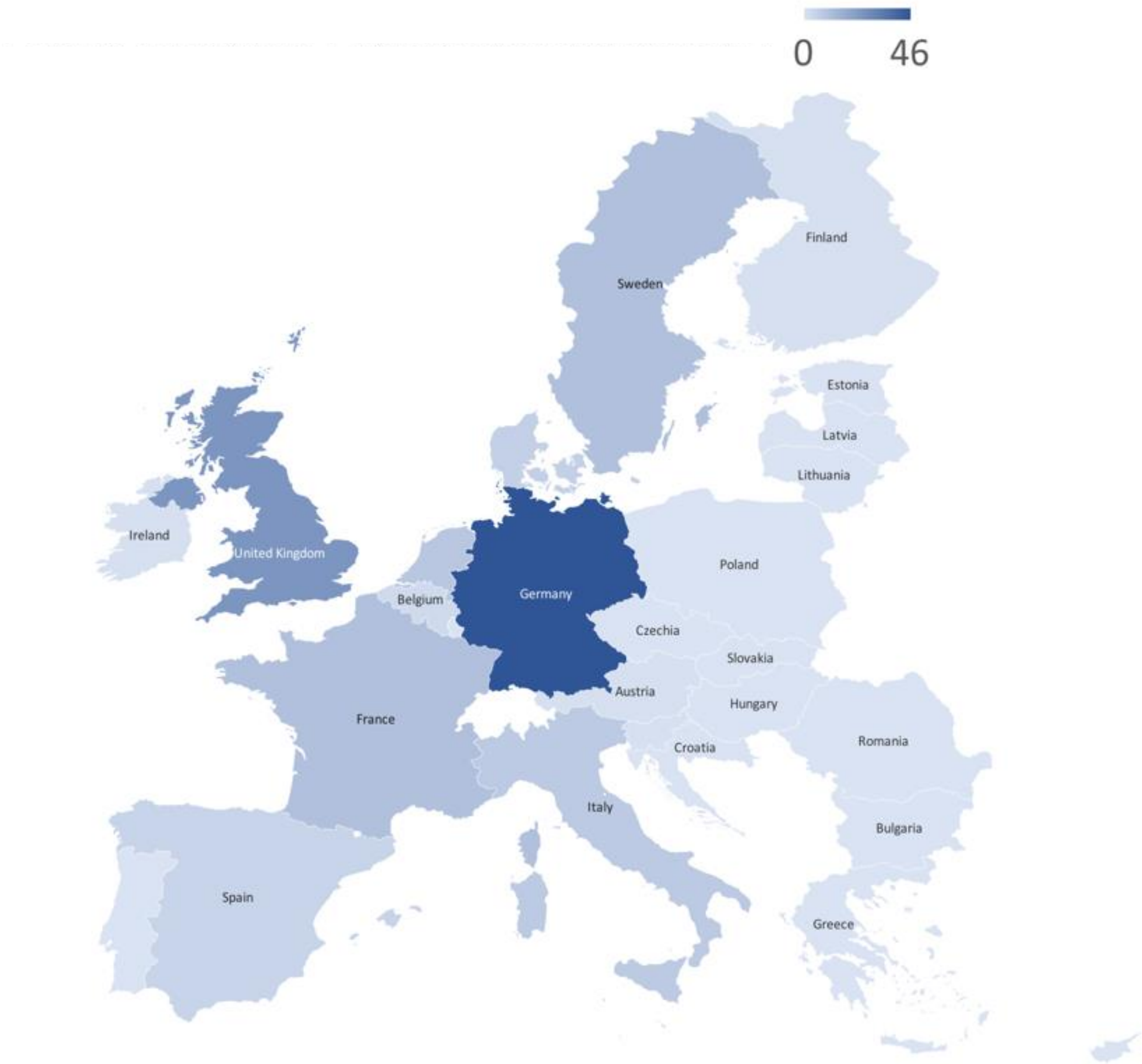
Figure 16 shows a breakdown of biotechnology patents by ICT type, with Large Capacity Information Analysis as the dominant digital technology used by all but two (Denmark and Hungary) of the 24 economies. Of these economies, 9 focus on just one technology; and while most of these economies filed fewer than 20 patents in biotechnologies, Denmark and Italy filed over 20 with a concentration on High Speed Network Digital Communication Technique for Denmark and Large Capacity Information Analysis for Italy.

Pharmaceuticals

Figures 17 and 18 give an insight into the filed health patents in pharmaceuticals. We can see that the number of economies filing these patents has fallen from 23 economies in the biotechnologies sector to 13 in pharmaceuticals for the period studied. The magnitude is also smaller, with no economies filing above 200 patents, and only Germany and the United Kingdom filing above 20 patents in this period and sector. Germany takes the lead here with 46 patents filed and the United Kingdom filed 25 patents in this period.

Figure 17: Total Number of Patents in Pharmaceuticals in the EU: 1990-2014

Source: PATSAT Global 2019 Spring Database



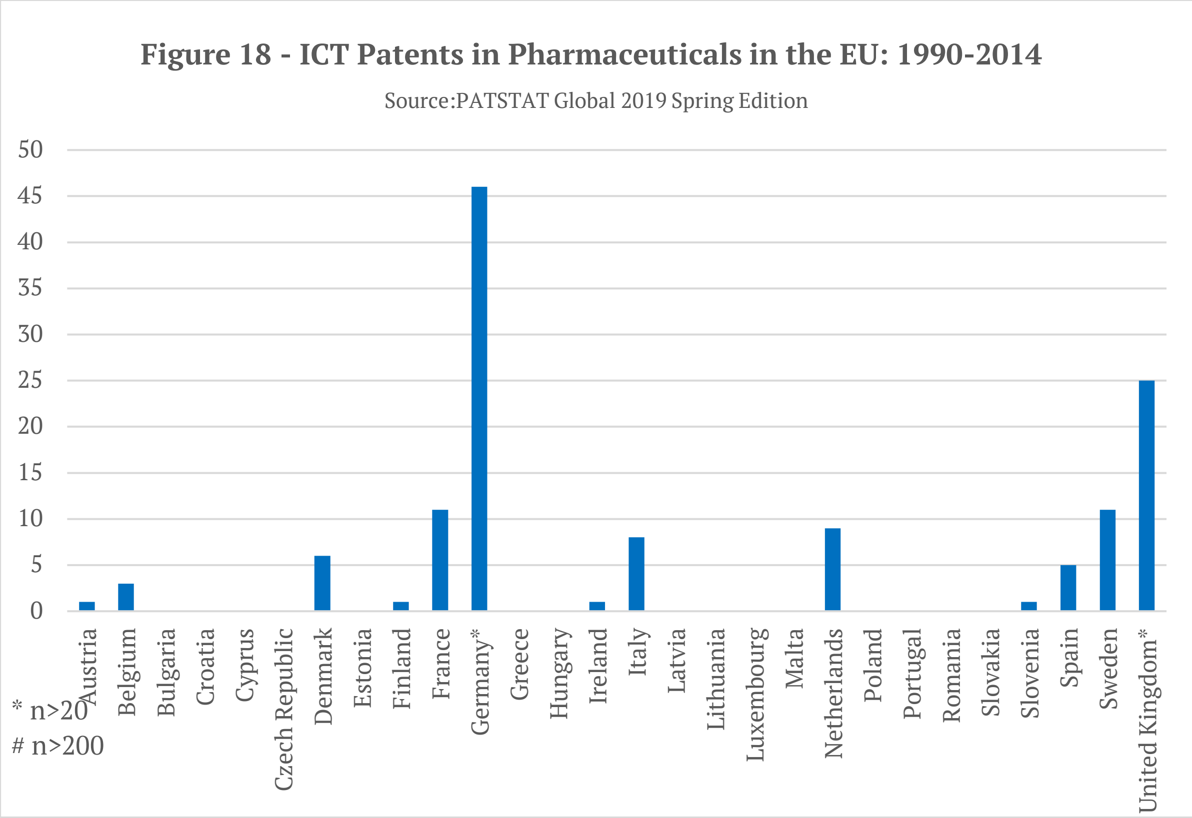


Figure 18 - ICT Patents in Pharmaceuticals in the EU: 1990-2014
Source:PATSTAT Global 2019 Spring Edition
50
45
40
35
30
25
20
15
10
5
0
Austria
Belgium
Bulgaria
Croatia
Cyprus
Czech Republic
Denmark
Estonia
Finland
France
Germany*
Greece
Hungary
Ireland
Italy
Latvia
Lithuania
Luxembourg
Malta
Netherlands
Poland
Portugal
Romania
Slovakia
Slovenia
Spain
Sweden
United Kingdom*
* n>20
# n>200

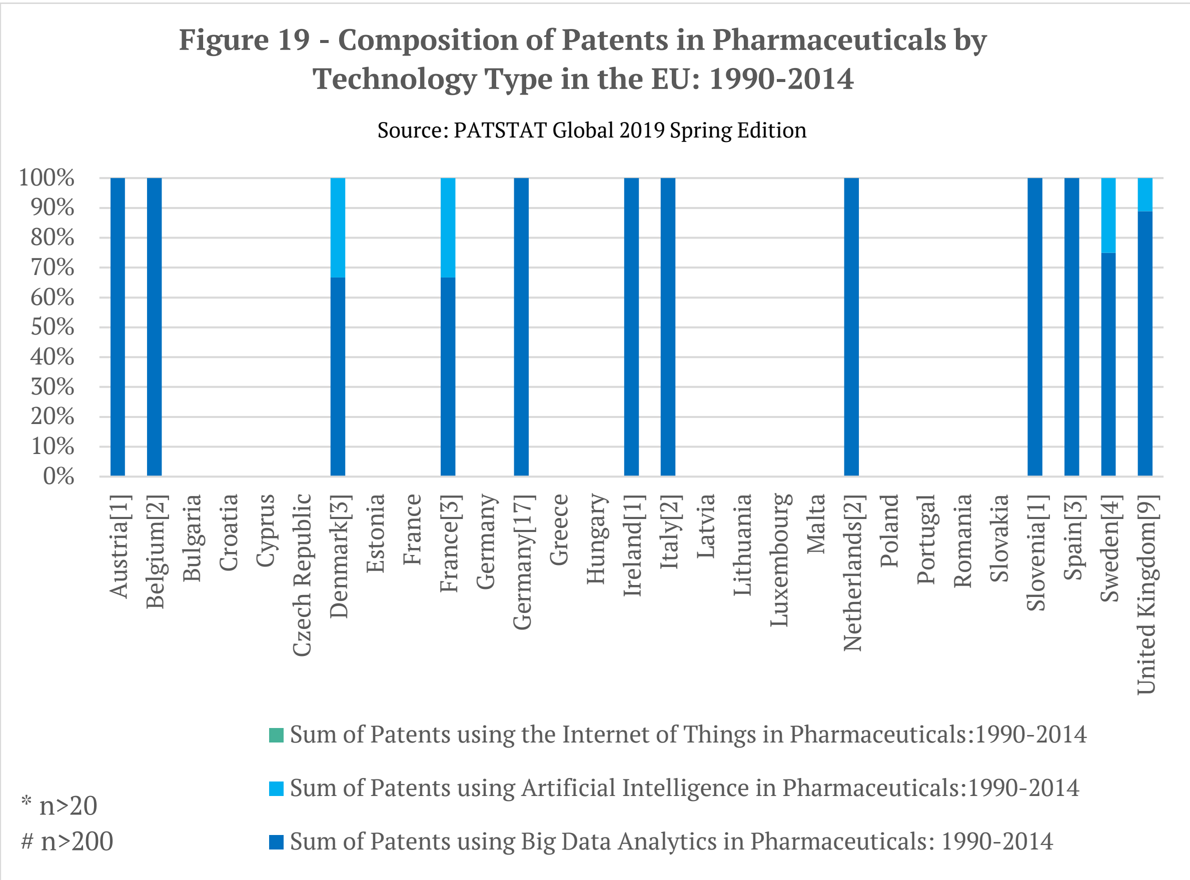
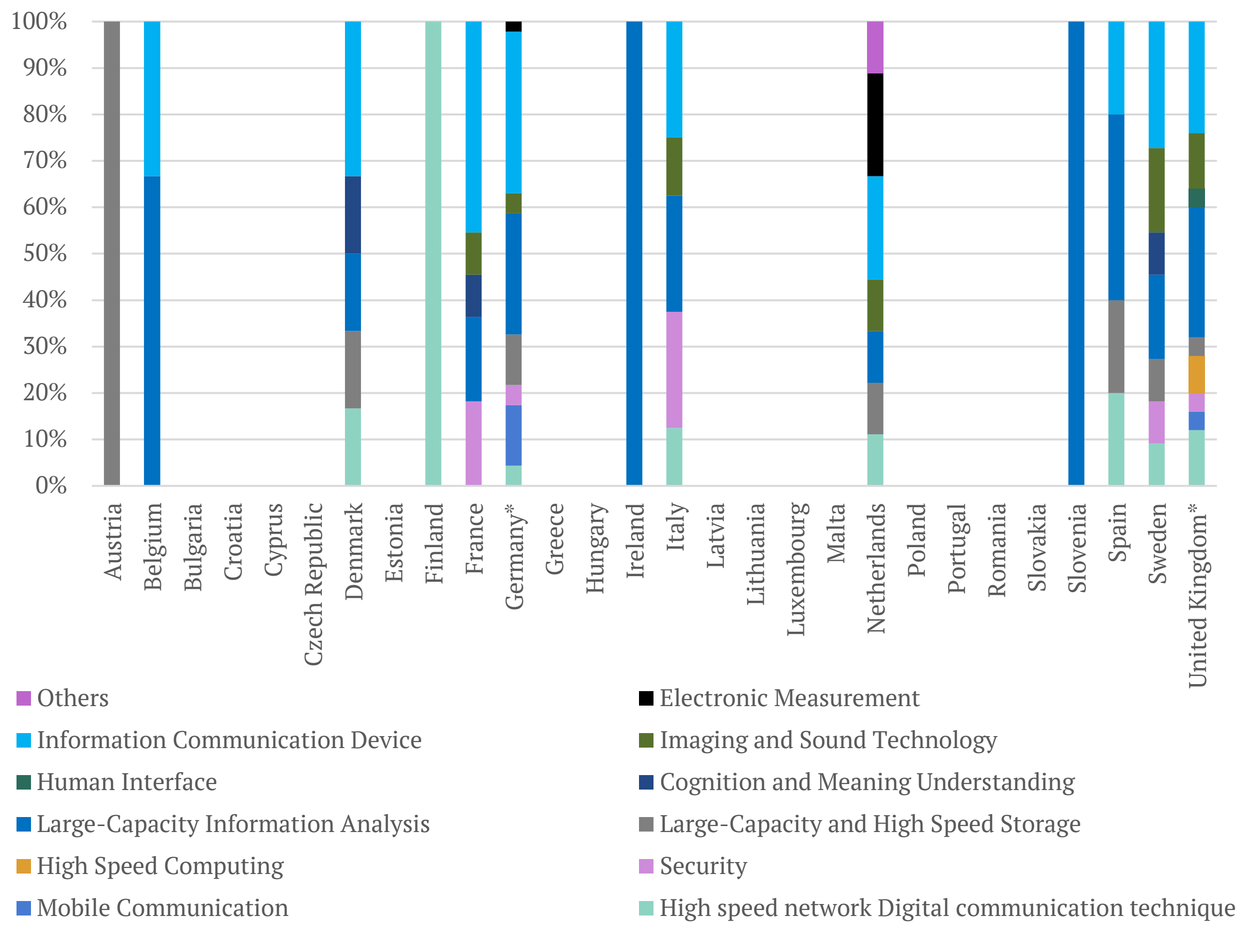


Figure 19 - Composition of Patents in Pharmaceuticals by Technology Type in the EU: 1990-2014
Source: PATSTAT Global 2019 Spring Edition
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Austria[1]
Belgium[2]
Bulgaria
Croatia
Cyprus
Czech Republic
Denmark[3]
Estonia
France
France[3]
Germany
Germany[17]
Greece
Hungary
Ireland[1]
Italy[2]
Latvia
Lithuania
Luxembourg
Malta
Netherlands[2]
Poland
Portugal
Romania
Slovakia
Slovenia[1]
Spain[3]
Sweden[4]
United Kingdom[9]
Sum of Patents using the Internet of Things in Pharmaceuticals:1990-2014
Sum of Patents using Artificial Intelligence in Pharmaceuticals:1990-2014
Sum of Patents using Big Data Analytics in Pharmaceuticals: 1990-2014
* n>20
# n>200

Figure 19 shows the composition of patents in pharmaceuticals broken down into the three focus areas: big data analytics, AI and IoT. Just as in biotechnologies above, IoT is not utilized in pharmaceutical patents. The overall mean number of patents filed was 4.57, with a standard deviation of 9.66. In pharmaceutical patents, big data analytics was utilized more than AI. The mean number of patents filed in big data analytics was 1.57, with a standard deviation of 3.4 while for AI the mean was 0.14, with a standard deviation of 0.34. Of the 28 economies studied, only 12 filed in pharmaceuticals during the period of study. However, for Germany, the top filer in pharmaceuticals, the patents filed using big data analytics made up less than half of the total filed in pharmaceuticals, and AI was not utilized at all. The second top filer in pharmaceuticals in this period, the United Kingdom, also had less than half of the patents filed utilizing the technologies we focus on in this study. Of those filed using these technologies, the majority utilized big data analytics and a smaller proportion utilized AI.

Figure 20- Composition of Patents in Pharmaceuticals in the EU by Digital ICT Breakdown: 1990-2014

Source: PATSTAT Global 2019 Spring Edition



* n>20
\# n>200

Figure 20 gives us an overall picture of all the digital technology patents filed in pharmaceuticals. Information Communication Device and Large-Capacity Information Analysis were the leading technology types utilized in these patents. While Ireland, Finland, Austria and Slovenia did not display heterogeneity in the types of technologies utilized, the majority (70%) of economies that filed patents in pharmaceuticals in this period did display heterogeneity in the kinds of technologies utilized.

MedTech

MedTech was a leading technology field in 2018 at the European Patent Office (EPO), and was the most popular category that year [11].

Figure 21: Total Number of Patents using Medtech in the EU: 1990-2014

Source: PATSAT Global 2019 Spring Database

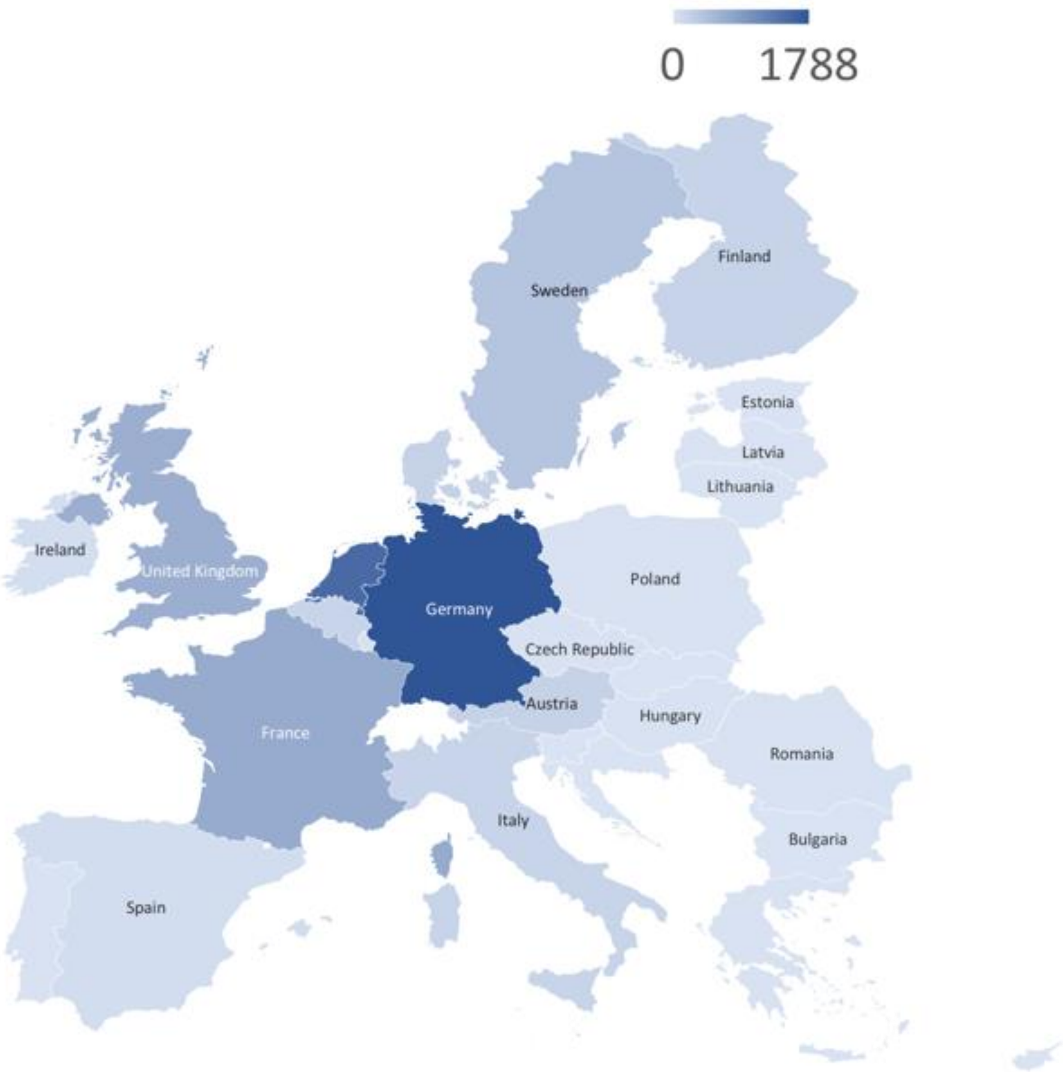
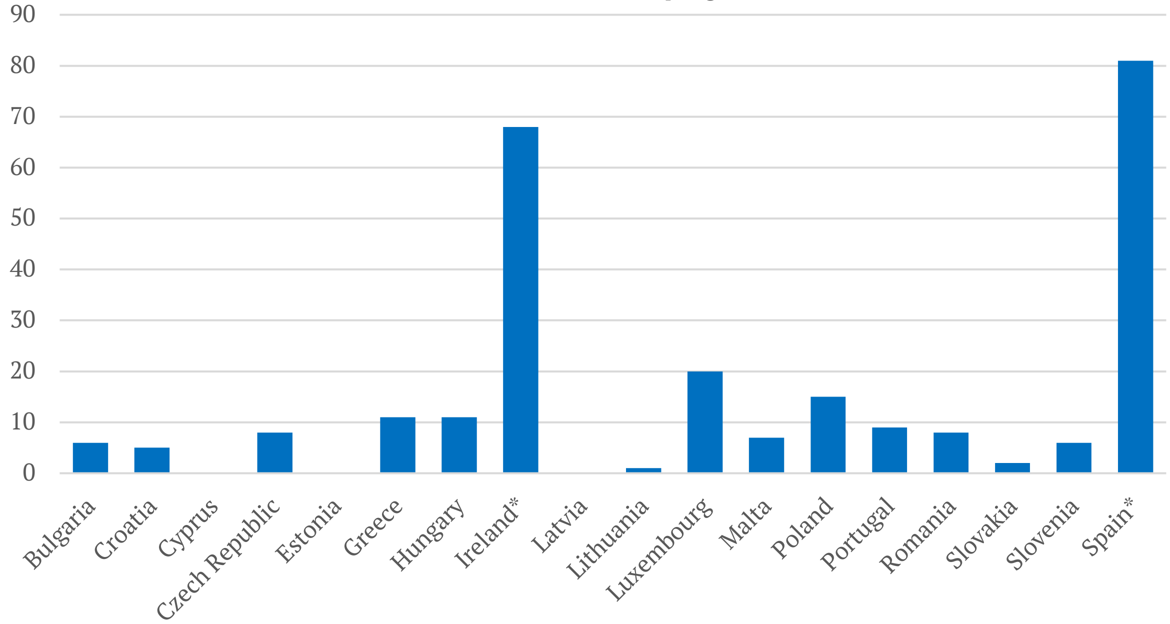


Figure 22 - Sum of ICT Patents in MedTech: 1990-2014 [Tier 1: <100]

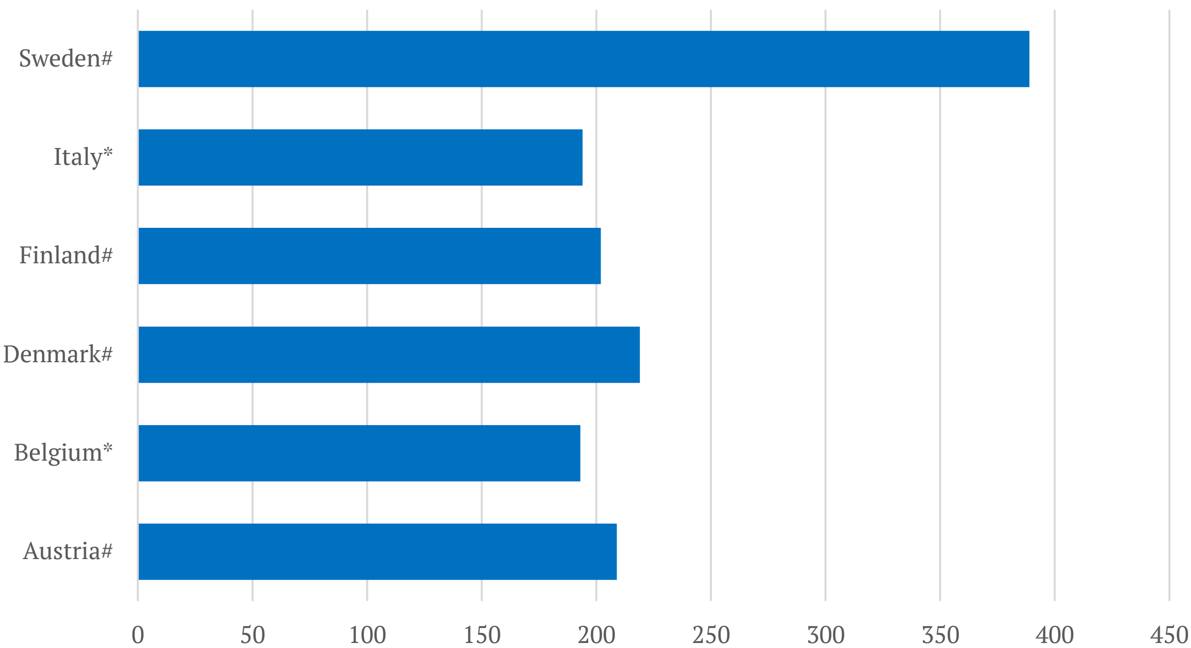
Source: PATSTAT Global 2019 Spring Edition



* n>20
# n>200

Figure 23 - Sum of ICT Patents in MedTech: 1990-2014 [Tier 2: >100]

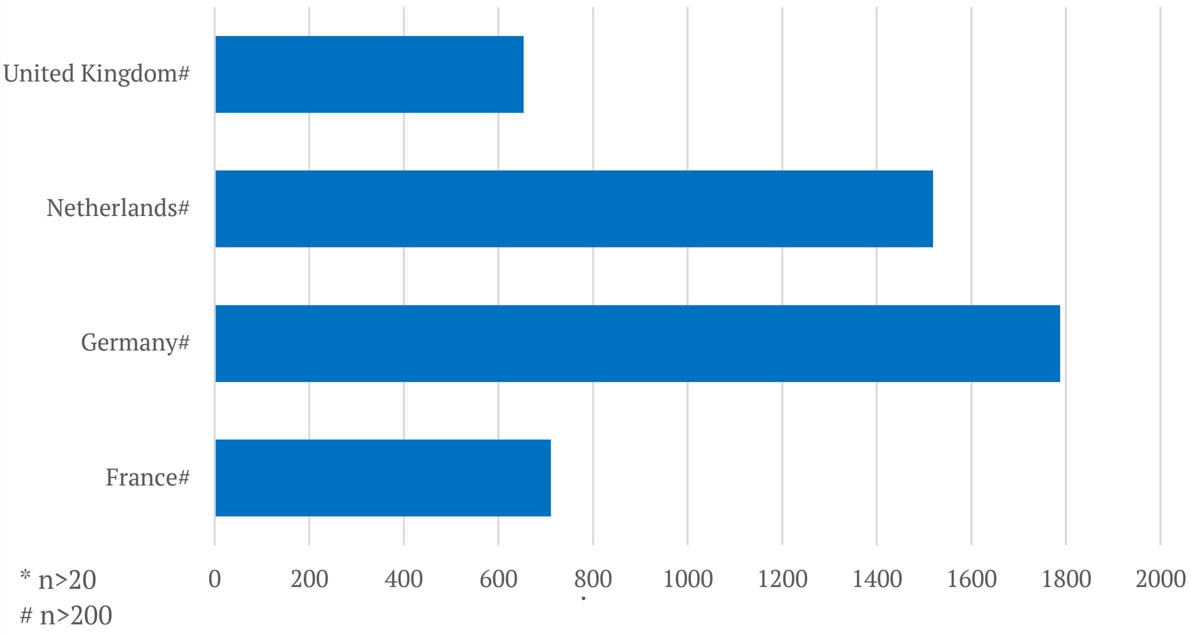
Source: PATSTAT Global 2019 Spring Edition



* n>20
# n>200

Figure 24 - Sum of ICT Patents in MedTech: 1990-2014 [Tier 3: >500]

Source: PATSTAT Global 2019 Spring Edition



Figures 21–24 show the level of patents filed in MedTech in three tiers: those below 100; those between 100 and 500; and those above 500. 25 out of the 28 economies studied filed a patent in MedTech. Out of the three sectors (biotechnologies, pharmaceuticals and MedTech), MedTech has the largest number of patents. The magnitude is also much higher, with the largest number of patents filed in biotechnologies and pharmaceuticals being Germany with 219 and 46 patents, respectively. In MedTech, Germany continued to take the lead, but with 1788 patents. Netherlands was second with 1588 patents; when compared with the 67 patents filed in biotechnologies and the 9 filed in pharmaceuticals, this magnitude filed in MedTech is considerable. Overall, the mean number of patents filed in MedTech was 226 with a standard deviation of 438. In comparison, the mean number in biotechnologies was 22.7 and in pharmaceuticals 4.57, thus illustrating the popularity of MedTech patents.

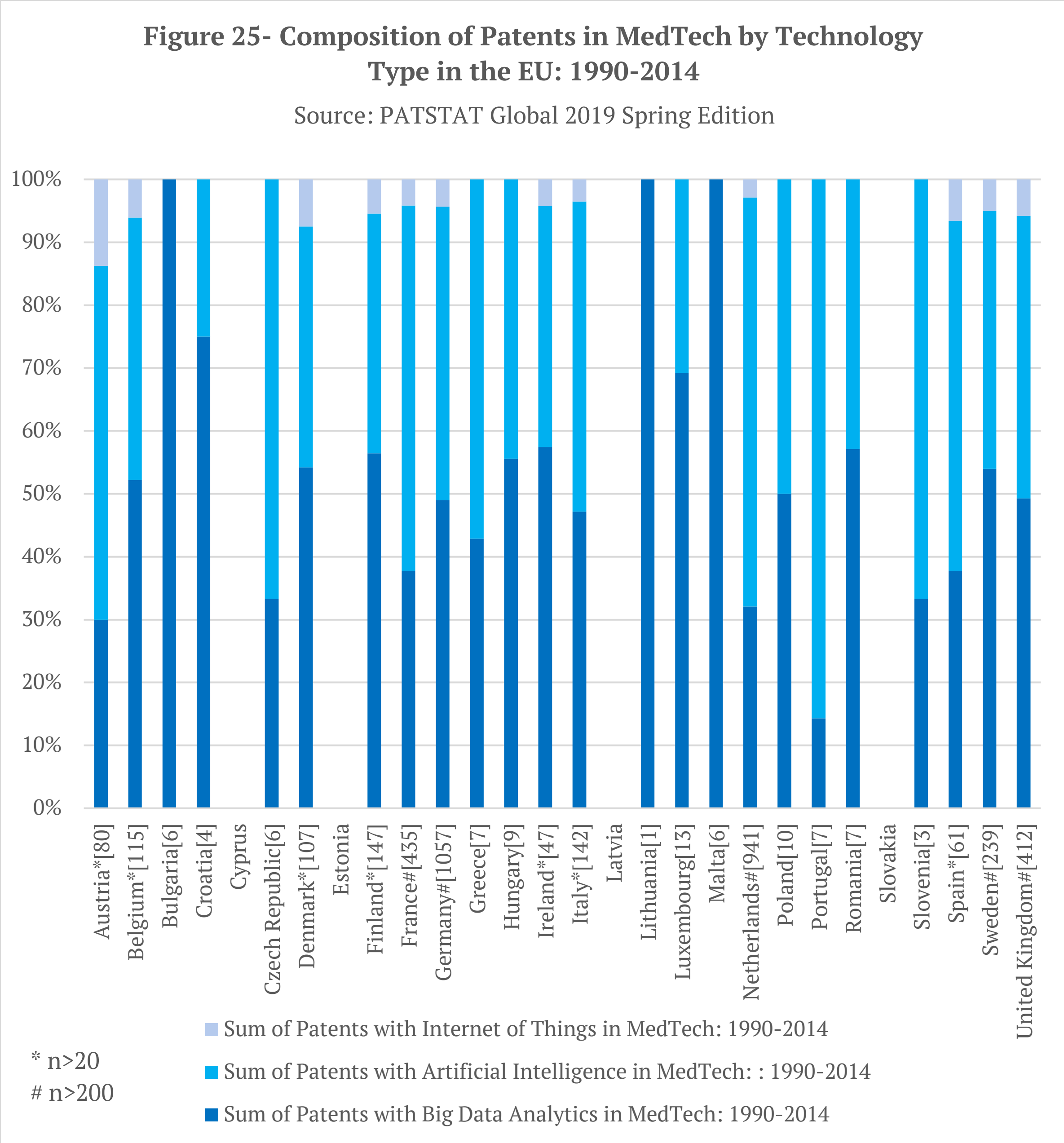


Figure 25 highlights the three digital technologies analysed in this report and shows that 12 economies filed patents in MedTech utilizing IoT; in comparison to the absence of IoT utilization in patents for biotechnologies and pharmaceuticals, as shown above. Of the 12 economies, Germany again filed the mount patents utilizing IoT with 46 patents, followed by the Netherlands with 27 patents. The mean number of patents filed in MedTech using IoT was 6.14, with a standard deviation of 10.6. In comparison, the mean number of patents in MedTech utilizing AI was 70.9, with a standard deviation of 146.4, and the mean number of patents utilizing big data analytics was 60.8, with a standard deviation of 113.5. Only 3 economies of the 28 European countries studied did not file a patent in MedTech, compared with 4 economies that did not file in biotechnologies and 15 that did not file in pharmaceuticals.

Figure 26 - Composition of Patents in MedTech in the EU by Digital ICT Breakdown: 1990-2014

Source: PATSTAT Global 2019 Spring Edition

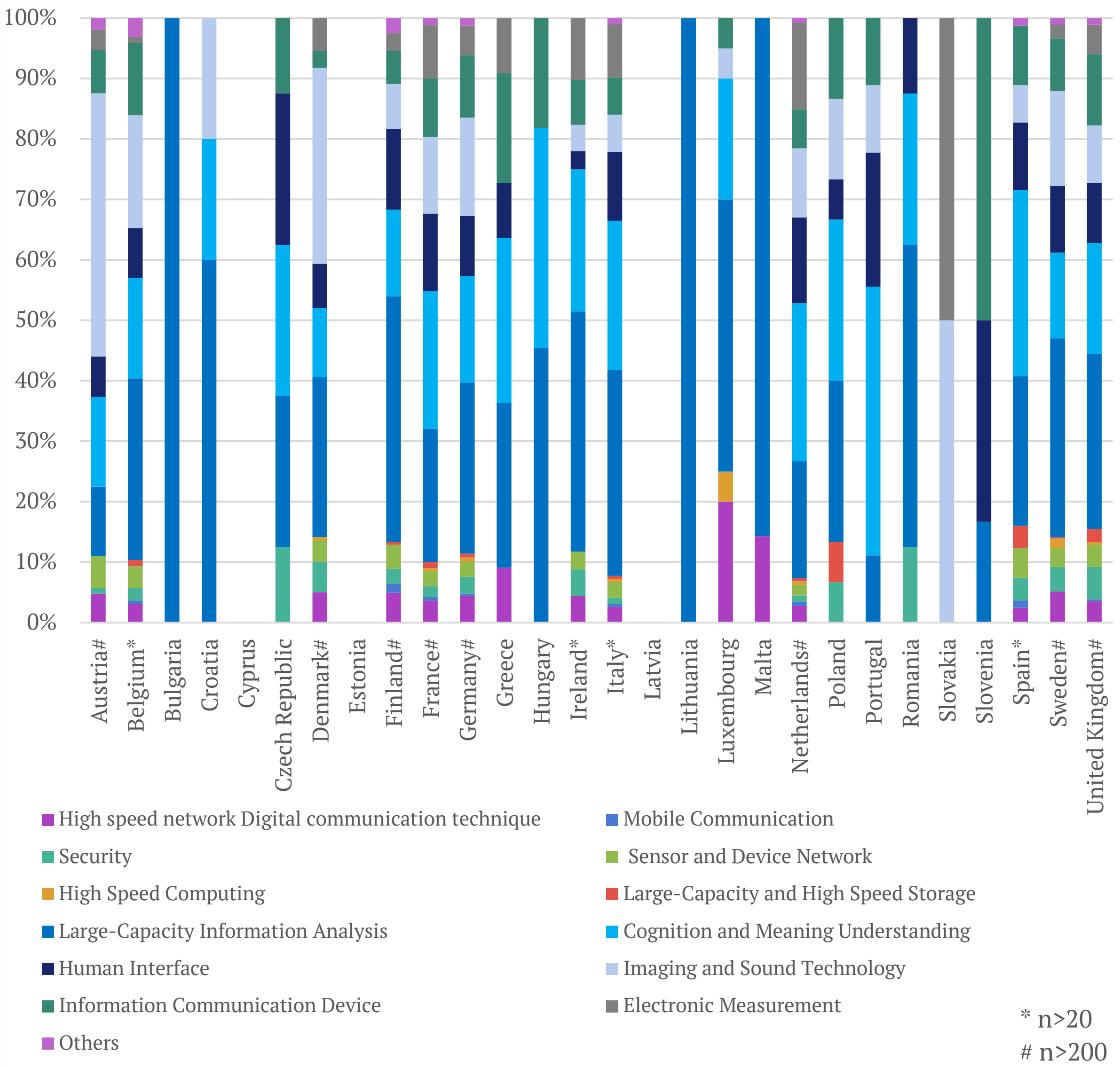


Figure 26 gives us a complete picture of all the different categories of digital technologies that were utilized in the MedTech patents. Except for Bulgaria and Lithuania (which only use Large-Capacity Information Analysis), all the economies filed patents in a variety of digital technologies, using on average 6.75 types of different digital technologies.

5. EXAMPLES OF PUBLIC PROGRAMMES BOOSTING DIGITAL HEALTH INNOVATION

This patent landscape analysis has revealed that the Netherlands, France, the United Kingdom and Germany lead the digital health innovation scene in the European Union. In all of these countries we also find policies designed to incentivize the digitalization of health (see Appendix, Table 2).

In the Netherlands the "Dutch Venture Initiative" was launched in 2016. The focus of this policy is on ICT, clean technologies and medical technologies, and has a yearly estimated budget range of €100 Million to €500 Million. This budget is on par with policies implemented by the United Kingdom and France but five to ten times the budget of policies targeting innovation in Germany. The focus in the Netherlands is on research and innovation for health and healthcare, and the policy aims to do this with direct and equity financing.

In Germany, there are three policies we highlight: the first is the "Research Programme on Human Machine Interaction – Bringing Technology to the People" launched in 2015 and has a yearly estimated budget range of €50 Million to €100 Million. The second is the German Centres of Health Research that aim to contribute to scientific study of widespread diseases, preventive medicine, diagnosis and personalized medicine. It also has a yearly estimated budget range of €50 Million to €100 Million.

The third is the "Learning Systems – Germany's Platform for Artificial Intelligence" set up in 2017 and has a yearly estimated budget range of €1 Million to €5 Million.

These policies focus on research and innovation in health and healthcare. While the first two focus on grants for innovation, the third focuses on clusters and other networking and collaborative platforms.

In the United Kingdom, the "Industrial Strategy Challenge Fund" was set up in 2017 and has a yearly estimated budget range of £100 Million to £500 Million; the "Innovate UK Funding Competitions" was set up in 2016; and "Catapult Centres" was set up in 2011, the latter two having unspecified budgets. These three policies also specify a focus on research and innovation in health and healthcare. While the first two focus on grants and funding to stimulate innovation, the third policy focuses on clusters and other networking and collaborative platforms. 2019 saw the set-up of NHSX: a body with an investment of more than 1 billion GBP annually to invest on projects incorporating technology into the healthcare system for patients and staff. In tandem, the Accelerated Access Collaborative (AAC) was set up in 2018 to speed up the process of innovation and direct it towards the most pressing needs of the community, for example, needs related to cancer, dementia and diabetes. Academic Health Science Centres (AHSC) and the Academic Health Science Network (AHSN) were set up to drive innovation to address the prevention of major diseases by focusing on bringing research insights from the university lab and turning them into treatments for patients.

France has the policy “Innovation 2030 – Worldwide Innovation Challenge”, which was set up in 2013 and has a yearly estimated budget range of €100 Million to €500 Million. This policy focuses on research and innovation in health and healthcare. One of the strategic pillars of the initiative is personalized medicine, aiming to fund projects focused on the “-omics” sciences (genomics, proteomics, etc.), synthetic biology, high resolution imaging (on tissue and even cellular levels) and big data. Moreover, it has fostered, targeted therapeutic interventions, whether pharmaceutical or interventional, through high resolution imaging. On the first phase of the programme, 15 firms received up to €200.000 each to develop innovative technological solutions in these domains.

6. KEY TAKEAWAYS

While the application of new digital technologies in the health sector is still in its infancy, some countries are generating and applying a wave of radical innovations. We can already see examples of applications in healthcare and pharmaceuticals, including optimizing clinical decisions, discovering new treatments and medications, and detecting and monitoring health conditions. In the future, the digital revolution holds the potential to facilitate personalized healthcare and precision medicine, or even enable remote robotic surgery and other health services with radical consequences for the quality and cost of healthcare.

Germany, the Netherlands, the United Kingdom and France are the current European economies leading the way in patent filings in health and healthcare. These economies lead in biotechnology, pharmaceuticals and MedTech, except for the Netherlands in pharmaceutical patents. Sweden is in the top 4 economies for pharmaceutical patents, as well as in the top 5 countries for MedTech research.

In terms of digital technologies utilized, these patents in these fields, big data analytics is the most popular technology in patents filed in biotechnologies and pharmaceuticals. The IoT features only in patents in MedTech in a minority of cases.

AI is still being used sparingly in patents in biotechnologies and pharmaceuticals, but has a prominent role in MedTech patents, with an average of 79.4 patents filed utilizing AI, with a standard deviation of 118. This is in comparison to an average of 68.1 patents filed utilizing big data analytics, with a standard deviation of 152, and 6.9 patents utilizing IoT, with a standard deviation of 11.

The most dominant digital ICT type for these patents is Large-Capacity Information Analysis, totalling 2257 patents in the whole period in these 28 economies. Cognition and Meaning Understanding is the second most popular ICT type with 1347 patents during the time period of the study. The least popular digital ICT employed in the patents were mobile communication at 42 patents and High Speed Computing at 45 patents.

A key factor in leading the digital revolution in health is the access to the raw material of digital technologies: data. Countries are increasingly establishing electronic health records (EHR) systems, genome sequencing and high-resolution medical imaging repositories and ubiquitous sensing, as well as IoT devices that monitor patients' health. However, only a few countries have achieved high-level data integration and explored the possibility of extracting data from EHRs and other data sources for research and innovation [12]. Healthcare systems still capture data in silos before separate analysis.

Countries leading the digital health revolution tend to have policy initiatives prioritizing the interoperability of health data, in particular promoting the personalized medicine sector. Examples include the German Centre of Health Research (Germany), the NIHR Biomedical Research Centre (BRC) and Academic Health Science Network (AHSN) (United Kingdom) and the Innovative Medicine Initiative (European Commission). These initiatives promote the exploration of combined health datasets and the establishment of a genome sequencing platform, developing innovations from the lab into treatments and therapies for use by patients. Fully unlocking the power of digital technologies to improve health systems will require further efforts in the standardization and interoperability of health datasets.

Promoting the upgrading of skills and collaborative research activities remains important policy priorities. The development of digital health technologies requires collaborative innovation activities between health professionals and technology developers. Public initiatives to effectively support this type of technology require policy designs that enable highly skilled collaborative endeavours. Leading countries in this area employ policy portfolios comprising, for example, block grants, competitive grants, grants requiring private-sector participation and instruments for start-ups such as grants and equity funding (for example, in the case of the European Innovative Medicines Initiative, the French Innovation 2030 or the Dutch Venture Initiative). Non-refundable block grants to institutional partnerships between universities, research centres and hospitals remain essential. Block grants are less flexible to target fast-moving technological priorities and depend on governments' annual budgets. However, they provide more stable funding than competitive grants. Partnerships generally use public funding to cover direct project costs for research and development activities and typically include the creation or improvement of digital infrastructures, researcher recruitment and graduate training.

Underlying all of this is a landscape of technology development that is uneven across Europe. The long-term implications of this is that some countries will be quicker to adopt technologies as a result of the more developed ecosystem of innovation linked to their healthcare system. What this report presents is an objective measure of the resulting innovations in these areas, as a result of or even in spite of these underlying realities. This gives an indication of trends for the future, and allows for a robust evaluation of the policies that have led to this outcome and an indication of the impact of more recent policy interventions in this space.

APPENDIX

Methodologies

In order to identify patents in the digital health sector, we relied upon the International Patent Classification (IPC) categorization. Patents are classified in different technological classes according to the technological area they are in. Patents can fall under one or multiple technological classes according to the technological components they contain. Our strategy to identify patents in digital health had two parts. First, we identified patents that have at least one technological class in a health-related class, as well as an ICT-related class. The vast majority of the digital health patents we identified fell into this category. The second element of our strategy consisted of identifying patents in the health class that cited relevant prior art in ICT classes. If an invention in the health sector cited an ICT patent as prior art then the ICT patent was important to the technological development and thus became part of our interest in this study. A minority of patents fell exclusively under this category; since most patents citing ICT prior, art would also have an ICT technological class.

The key health fields we considered were MedTech, biotechnologies and pharmaceuticals. We identified these sectors based on IPC's technology concordance tables [13]. Patents in ICT encompass 13 areas defined according to the specific technical features and functions they accomplish [14]. Table 1 presents these 13 ICT areas. In our analysis, we present the breakdown for each of these 13 areas as well as the following aggregations: big data analytics (comprising large-capacity and high-speed storage and large capacity information analysis); AI (comprising cognition meaning and understanding, human-interface and imaging and sound technology, which often use ML algorithms); and IoT (comprising sensor and device networks).

Table 1. ICT areas

Technological area	Sub areas
1. High speed network	Digital communication technique; Exchange, selecting; Others
2. Mobile communication	
3. Security	Cyphering, authentication; Electronic payment
4. Sensor and device network	Sensor network; Electronic tag; Others
5. High speed computing	
6. Large-capacity and high-speed storage	
7. Large-capacity information analysis	Database; Data analysis, simulation, management
8. Cognition and meaning understanding	
9. Human interface	
10. Imaging and sound technology	Imaging technique; Sound technique
11. Information communication device	Electronic circuit; Cable and conductor; Semiconductor; Optic device; Others
12. Electronic measurement	
13. Others	Computer input-output; Other related technique

Source: OECD [14]

The number of patents with inventors and applicants from multiple countries has been increasing in recent years, reflecting the greater openness and internationalization of science and technology activities. We used the priority date[1] of application as inventions' reference date, and inventors' and applicants' country(ies) of residence as reference country. Patents with multiple reference countries can either be partly attributed to each country (fractional counts) or fully attributed to each country (whole counts) [15]. In this study we used the whole counting approach since we were interested in understanding which countries contributed to generating the new knowledge that new digital health inventions embed.

[1] Priority date is the earliest filing date in PATSTAT

Examples of policies

Table 2. Examples of Policies for Research and Innovation in Health and Healthcare in the European Union

Policy Name	Start date	Evaluation	Yearly budget	Country	Theme(s)
Dutch venture initiative	2016	No	100M-500M	Netherlands	Access to finance for innovation; Near-to-market digital technology; Research and innovation for health and healthcare; Research and innovation for sustainable development; Targeted support to SMEs; Targeted support to young innovative enterprises
Innovative medicines initiative (Societal challenges health Horizon2020)	2014	No	100M-500M	European Union	Financial support to business R&D and innovation; Near-to-market digital technology; Research and innovation for health and healthcare; Research and innovation for sustainable development
Research programme on human-machine-interaction: "bringing technology to the people"	2015	No	50M-100M	Germany	Near-to-market digital technology; Research and innovation for health and healthcare
Learning systems—Germany's platform for artificial intelligence	2017	No	1M-5M	Germany	Artificial intelligence; Cluster policies; Digital transformation of firms; Research and innovation for health and healthcare
Flanders holding company	1995	Yes	More than 500M	Belgium-Flanders	Access to finance for innovation; Near-to-market digital technology; Research and innovation for health and healthcare; Research and innovation for sustainable development; Targeted support to young innovative enterprises

Industrial strategy challenge fund	2017	Yes	100M-500M	United Kingdom	Artificial intelligence; Financial support to business R&D and innovation; Horizontal policy coordination; Interdisciplinary research; Near-to-market digital technology; Research and innovation for health and healthcare
Innovate UK funding competitions	2016	Yes	N.A.	United Kingdom	Financial support to business R&D and innovation; Near-to-market digital technology; Non-financial support to business R&D and innovation; Research and innovation for health and healthcare
Priority directions in science	2018	No	N.A.	Latvia	Multi-stakeholder engagement; National STI plan or strategy; Near-to-market digital technology; Public research strategies; Research and innovation for health and healthcare; Research and innovation for society strategy
Active and assisted living programme	2014	Yes	50M-100M	Switzerland	Digital transformation of firms; Financial support to business R&D and innovation; Research and innovation for health and healthcare; Targeted support to SMEs
Benefit programme (intelligent technologies for older people)	2008	No	1M-5M	Austria	Competitive research funding; Interdisciplinary research; Near-to-market digital technology; Research and innovation for health and healthcare
Innovation 2030 – worldwide innovation challenge	2013	No	100M-500M	France	Financial support to business R&D and innovation; Near-to-market digital technology; Research and innovation for health and healthcare; Stimulating demand for innovation and market creation
Precommercial public procurement	2017	Yes	20M-50M	Lithuania	Near-to-market digital technology; Research and innovation for health and healthcare; Research and innovation for sustainable development; Stimulating demand for innovation and market creation

Catapult centres	2011	No	N.A.	United Kingdom	Cluster policies; Collaborative research; Commercialisation of public research results; Near-to-market digital technology; Non-financial support to business R&D and innovation; Research and innovation for health and healthcare
Growth plans	—	No	N.A.	Denmark	Business innovation policy strategies; Digital transformation of firms; Near-to-market digital technology; Research and innovation for health and healthcare; Transfer and linkages strategies
Thematic programmes financing public research	—	No	100M-500M	Norway	Competitive research funding; Near-to-market digital technology; Research and innovation for health and healthcare; Research and innovation for sustainable development

Source: OECD STIP compass database

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