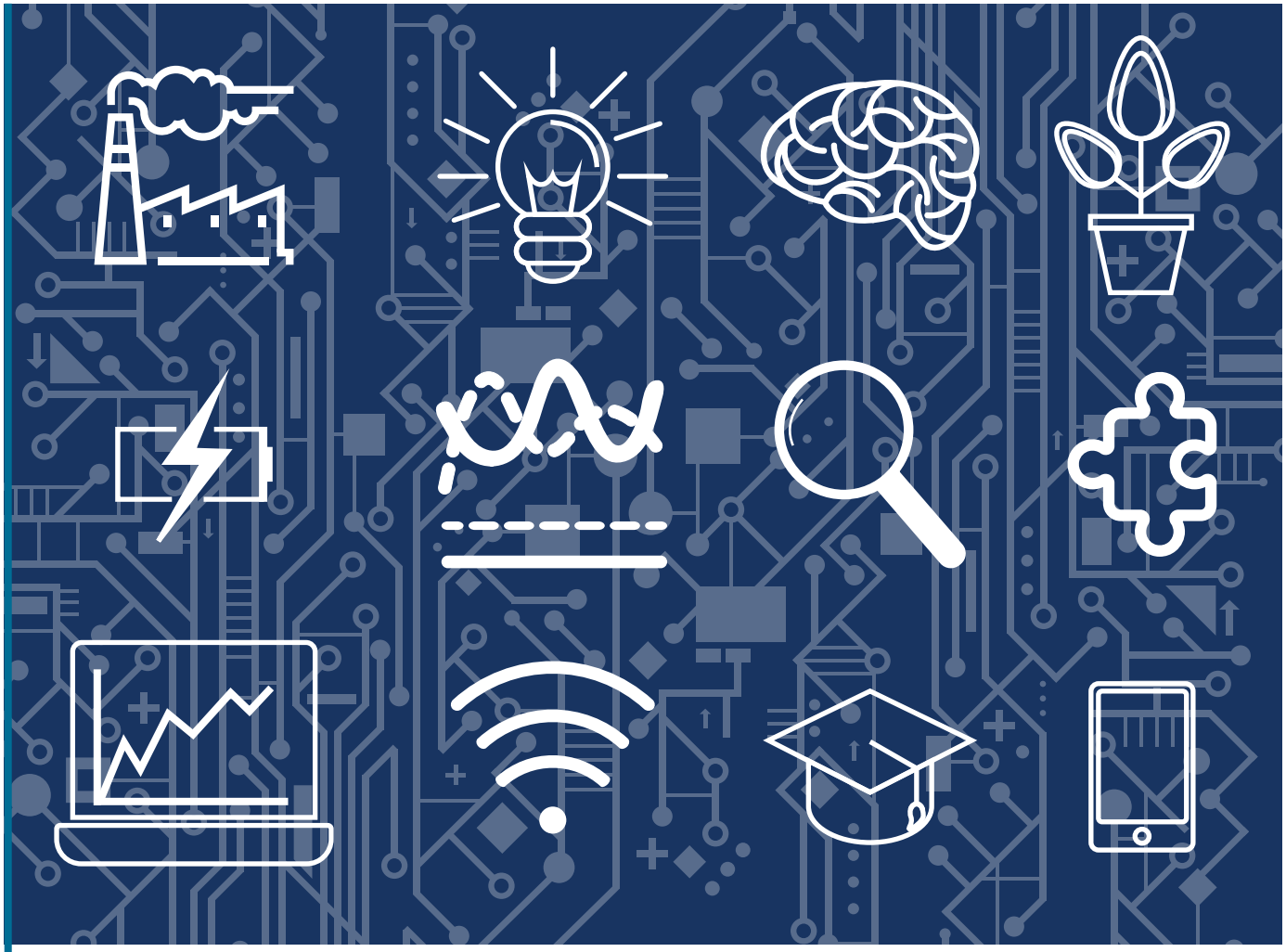
Intellectual Property Office

Artificial Intelligence

A worldwide overview of AI patents and patenting by the UK AI sector



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Executive summary

Artificial Intelligence (AI) is growing at a great pace and is spreading across many industry sectors. AI as a concept was first coined in the 1950s and has been the basis for a plethora of science fiction novels and movies. Now, 60 years later, AI is rapidly entering nearly every industrial sector and is increasingly embedded into modern society.

The UK government is dedicated to advancing the UK's AI sector, which is estimated[1] to add £630bn to the UK economy by 2035; AI is one of the four Grand Challenges forming the UK government's Industrial Strategy which aims to boost the productivity and earning power of people across the UK, and to increase the level of investment in Research and Development (R&D) from 1.7% to 2.4% of GDP by 2027.

Earlier this year, the World Intellectual Property Organization (WIPO) published a report on the technology trends in AI (WIPO, 2019)[2], and this study aims to look at similar trends with more of a focus on the UK. It provides an overview of the AI patent landscape across the world and investigates the past and current trends in this rapidly advancing area of technology. It is one of the first to look more closely at patenting activity within the UK's AI sector and how this compares with other countries. It provides insights into the leading UK-based applicants in the field, the location and extent of their future markets, as well as attempting to identify specific strengths within the UK's AI sector.

The rapid growth of worldwide patenting in AI technologies over the past decade has seen increases of over 400% in the number of published AI patent applications. The UK AI sector has seen its patenting activity more than double over the same period. Around 88% of AI-related patents first filed in the UK are also protected elsewhere, and this is in contrast with two big global players, the US and China, who have 53% and 19% respectively of patents protected in other jurisdictions. Patentees generally only take on the additional costs and delays of extending protection to other countries if they deem it worthwhile[3]; the large proportion of UK patents protected elsewhere therefore reflects a perceived importance of commercialising AI-related patents internationally, which may be driven in part by the larger markets found outside the UK.

Some of the leading applicants in AI patenting worldwide include software companies such as IBM and Microsoft, and manufacturing and consumer electronics firms such as Philips and Sony. UK-based applicants and inventors are ranked sixth worldwide in terms of the absolute level of AI patenting activity. Interestingly, there are more US-based applicants filing for AI-related patents in the UK than UK-based applicants. Technology related to neural networks has shown significant growth across the world over the past five years. The UK in particular has seen larger proportional increases than the global trends in AI-related technologies related to transport, image processing and telecommunications.

1 https://www.digicatapult.org.uk/technologies/artificial-intelligence/
2 WIPO, 2019 - https://www.wipo.int/edocs/pubdocs/en/wipo_pub_1055.pdf
3 OECD Patent Statistics Manual, 2009, pp 71-73 - https://www.oecd-ilibrary.org/science-and-technology/oecd-patent-statistics-manual_9789264056442-en

Introduction

The term 'Artificial Intelligence' (AI) refers to those computer systems capable of performing tasks that would normally require some intelligence if done by humans. We interact with AI systems on a regular basis, for example in transport, e-mail, banking and social networking, and AI is fast becoming embedded into our everyday lives.

The UK government is committed to boosting the UK's emerging AI sector[4,5]. In 2017, an independent review of the AI industry in the UK was carried out by Professor Dame Wendy Hall and Dr. Jérôme Pesenti[6]. The review recommended a number of ways to boost the UK's emerging AI sector at home and internationally. In response to these recommendations, the UK government published a Sector Deal[7] that sets out a number of commitments from government and industry.

From an intellectual property (IP) perspective, this report follows on from the efforts of WIPO[8] earlier this year and provides an overview of the AI sector through a patent-focused lens, looking at differences across countries and concentrating on the industries in the UK that use this patented AI technology.

Glass.ai[9] is a UK technology company that provided a list of AI companies that are active in the field by analysing the public content of their websites. A number of UK AI companies were selected from the Glass.ai results to form case studies for this report. Not all companies from the Glass.ai results are found in the patent dataset because the computational and mathematical nature of AI means it can fall within fields that are legally excluded from patentability, and this varies by jurisdiction. This may encourage open source development or non-patent publications[10].

4 https://www.gov.uk/government/topical-events/the-uks-industrial-strategy
5 https://www.gov.uk/government/publications/artificial-intelligence-sector-deal
6 Hall, W and Pesenti, J - 'Growing the Artificial Intelligence Industry in the UK', 2017 - www.gov.uk/government/publications/growing-the-artificial-intelligence-industry-in-the-uk
7 https://www.gov.uk/government/publications/artificial-intelligence-sector-deal/ai-sector-deal
8 https://www.wipo.int/edocs/pubdocs/en/wipo_pub_1055.pdf
9 www.glass.ai
10 See https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3233463 for a review by the National Endowment for Science, Technology and the Arts (NESTA) mapping the development of AI general purpose technology

A brief history of AI

Although AI has been around as a concept since the 1950s, a lack of enabling technologies and fluctuating levels of interest and investment led to a lack of tangible benefits from the technology. Computational advancements in modern times, such as processing power and data storage, have resulted in technology catching up with theoretical advances and over the last two decades there has been a steady increase in advancements in AI, some of which are noted below.

1997: IBM supercomputer, Deep Blue, beats world chess champion Garry Kasparov[11].

2002: First household robot is introduced – a vacuum cleaner called Roomba[12]. Amazon uses automated systems to provide product recommendations.

2008: Google introduces speech recognition in their app, pioneering a new approach using neural networks[13].

2010: Microsoft Xbox launches Kinect to track human body movement in their video gaming devices[14].

2011: Apple releases Siri[15]. IBM Watson computer beats champions of TV game show Jeopardy[16].

2012 to present: Increased investment in AI, e.g. in autonomous vehicles. Google's AlphaGo, created by London-based DeepMind, beats champion Go player[17]. Access to big data and advancements in deep learning lead to new developments.

11 https://www.ibm.com/blogs/think/2017/05/deep-blue/
12 http://media.irobot.com/2002-09-18-iRobot-Introduces-Roomba-Intelligent-FloorVac-The-First-Automatic-Floor-Cleaner-In-The-U-S
13 https://www.nytimes.com/2008/11/14/technology/internet/14voice.html
14 https://www.techradar.com/uk/news/gaming/microsoft-xbox-kinect-release-date-10-november-710465
15 https://edition.cnn.com/2011/10/04/tech/mobile/siri-iphone-4s-skynet/index.html
16 https://www.theguardian.com/technology/2011/feb/17/ibm-computer-watson-wins-jeopardy
17 https://techcrunch.com/2017/05/24/alphago-beats-planets-best-human-go-player-ke-jie/

Case Study: DeepMind

DeepMind Technologies[18] is a UK-based AI company. It was founded in 2010 by Demis Hassabis, Shane Legg and Mustafa Suleyman, and was acquired by Google in 2014 for £400 million[19] so it is now part of the Alphabet group. The company is well-known for developing AlphaGo, which became the first computer program to beat a professional Go player on a full-sized board in 2016[20].

The majority of DeepMind's patents relate to the architectural details of neural networks, and to aspects of training a neural network. Their inventions therefore represent innovations that have a potentially far-reaching impact in a variety of fields. DeepMind have also pursued patents relating to some of these fields, examples of which are described below:

- WO 2018/048934 relates to the synthesis of audio data using a neural network, which could be used in text-to-speech systems.
- WO 2018/081089 relates to a technique of performing language modelling tasks on text sequences using neural networks, and has applications towards machine translation, text summarisation, and speech recognition. In each of these application fields, an understanding of linguistic context enables more accurate outputs to be generated.
- US 2014/0185959 relates to an image processing algorithm which identifies the texture or patterning of objects in an image (such as striped or spotted items of clothing), which has applications towards image classification.
- EP 3398114 relates to a method of image compression, where salient features are recognised using a neural network and then used to summarise the contents of the image.

DeepMind have typically applied for patents via the WIPO (PCT) route, indicating that they seek to commercialise their inventions in the global marketplace.

In 2014 London-based DeepMind was acquired by Google for £400 million

18 https://deepmind.com/
19 https://www.theguardian.com/technology/2014/jan/27/google-acquires-uk-artificial-intelligence-start-up-deepmind
20 https://techcrunch.com/2017/05/24/alphago-beats-planets-best-human-go-player-ke-jie/

Worldwide patent analysis

Data overview

The AI patent dataset on which this study is based was obtained from the European Patent Office's (EPO) PATSTAT[21] data product (Autumn 2018 Edition) following detailed discussion and consultation with UK patent examiners who are experts in the field. 2017 is the last complete calendar year available using this edition of the PATSTAT data source. PATSTAT contains worldwide bibliographical and legal status published patent data and has become a standard in the field of patent intelligence and statistics[22].

There is no widely agreed definition of what constitutes AI and reaching such a definition is hampered by the wide-ranging application areas of AI. Further, the rapidly evolving nature of the technology makes it difficult to determine an exhaustive list of situations where AI may be applied. The approach taken in this report is therefore to seek a representative cross-section of patents that each have a high presumption of relating to AI. This was done by retrieving an initial set of patents that are classified in areas that relate specifically to the development of AI techniques or to the use of specific AI techniques. To avoid excluding AI patents unnecessarily, the initial set was combined with a set of patents whose abstract contains any keyword which is considered to relate specifically to AI.

The dataset was pre-processed as follows[23]:

- Utility models and other documents not classified as invention patents were removed;
- Patent applications were restricted to those having a first publication date in the range 1998-2017 (inclusive); patent families were also restricted to those having a first publication date of any member in the range 1998-2017 (inclusive);
- Applicant and inventor country information is based on the PATSTAT person country code and was extrapolated to cover blank entries where possible.

21 https://www.epo.org/searching-for-patents/business/patstat
22 Further details on how to analyse and interpret patent data can be found in the Patent Guide, https://www.gov.uk/government/publications/the-patent-guide
23 See Appendix 2 for further details

The AI patent dataset used for this study includes over 85,000 patent families comprising over 160,000 patent applications. The search strategy is broadly analogous to that taken by other recent studies (WIPO, 2019); it is intended that the narrower approach adopted here forms the basis of a complementary study[24].

This report is based on the analysis of published patent application data rather than granted patent data. Published patent application data gives more information about technological activity than granted patent data because a number of factors determine whether an application ever proceeds to grant; these include the inherent lag in patent processing at national IP offices worldwide and the patenting strategies of applicants who may file more applications than they ever intend to pursue.

Throughout this report, patents are counted either as single published patent applications or as patent families depending on the context. A 'patent application' refers to a single patent application made in one jurisdiction and published in that jurisdiction. Patent applications are counted once regardless of the number of subsequent publications[25]. A 'patent family' refers to a group of patent applications made and published in different jurisdictions. Each member of a patent family is considered to relate to the same invention. A patent family is counted once regardless of the number of members or publications it contains.

24 See Appendix 1 for further details

25 A patent application may be re-published during processing (e.g. at later search; following correction; at grant); in this dataset each application is counted only once under its year of first publication

International landscape

The worldwide growth in AI over the past two decades can be seen in Figure 1, which shows the total worldwide number of AI patent applications by year of first publication. The purpose of a patent is to seek a monopoly over the exploitation of an invention, and so the number of published applications each year is used here as an overall measure of the level of commercialisation in the field of AI. In Figure 1, the more frequent publications in recent years therefore reflects the increased level of patenting activity occurring in the field of AI.

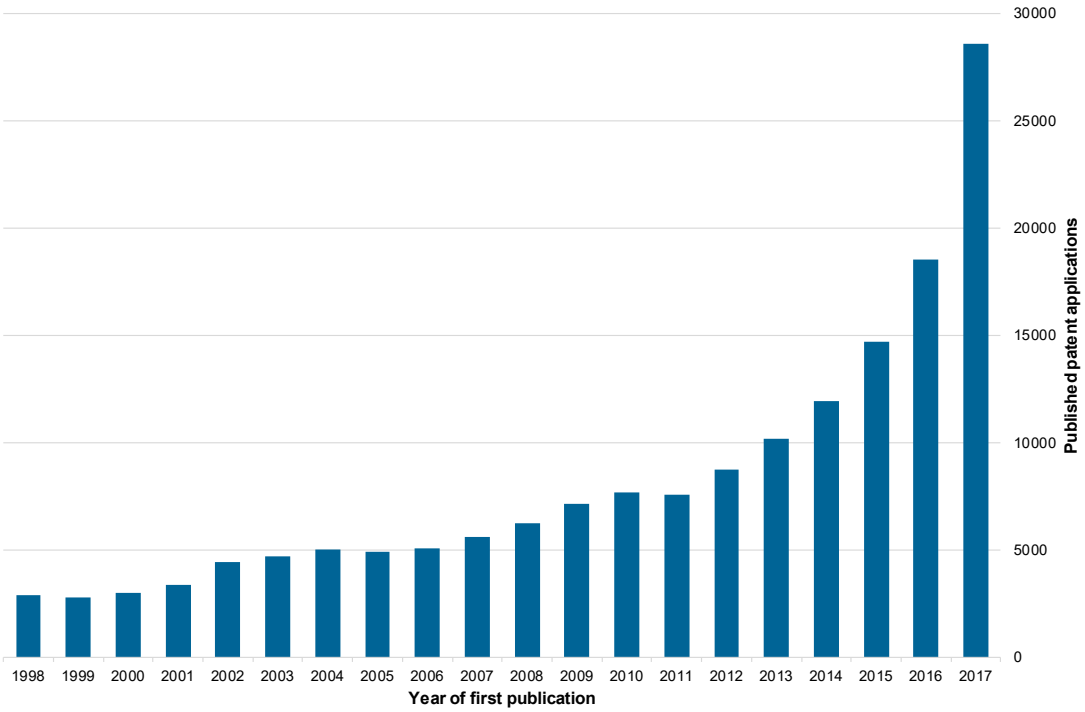

Figure 1: AI patent applications by year of first publication

Geography of patent filings

Figure 2 shows the overall level of patent coverage for AI patents between 1998 and 2017. Each patent application is counted once under the country of publication[26]. The US and China lead by a significant margin overall, and the remainder of the IP5 offices[27] follow. Germany is in seventh place which reflects the strength of the German AI market, given that total patent protection in Germany is also inclusive of granted EP patents[28].

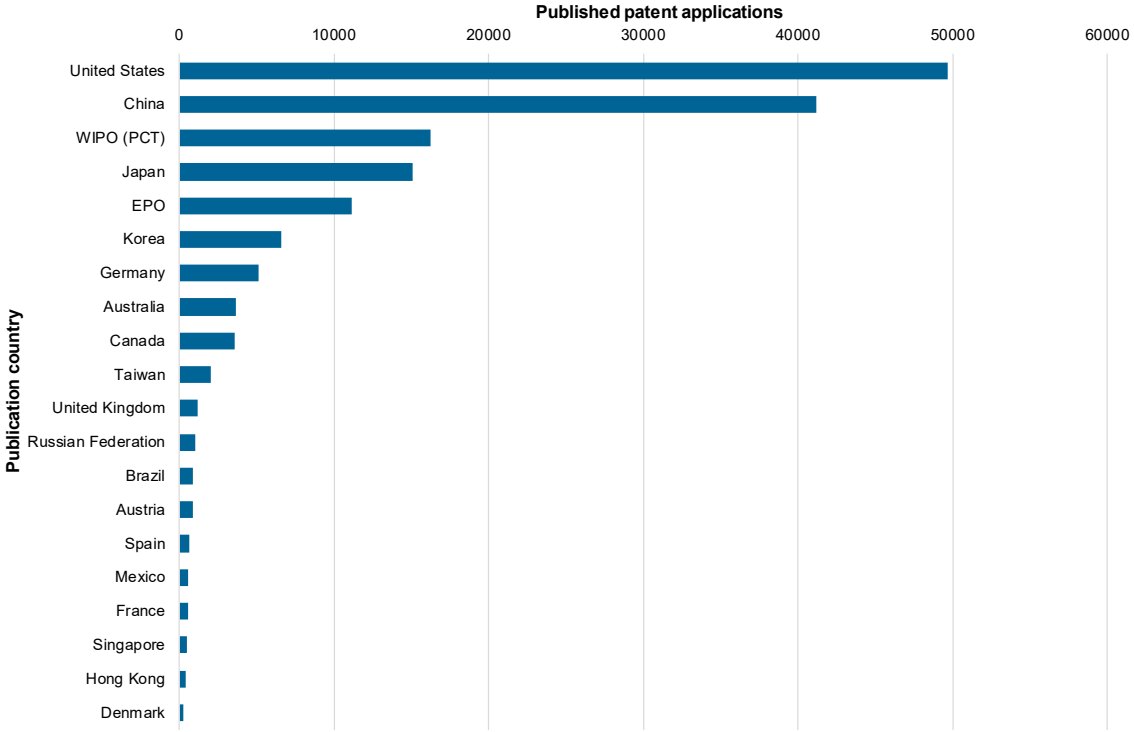

Figure 2: AI patent applications by publication country, 1998-2017

26 Further information on WO (PCT) and EP patent applications is discussed in Appendix 6. Note in particular that a high proportion of EP patent applications are applicable to all Member States of the European Patent Organisation. In Figure 2, the majority of EP patent applications therefore relate also to the UK, Germany, Austria, Spain, France and Denmark. The applications attributed to these countries are those filed directly with the respective national IP offices

27 IP5 is the name given to a forum of the five largest IP offices - the European Patent Office (EPO), the Japan Patent Office (JPO), the Korean Intellectual Property Office (KIPO), the National Intellectual Property Administration of the People's Republic of China (CNIPA) and the United States Patent and Trademark Office (USPTO) - https://www.fiveipoffices.org/index

28 EP patent applications have a designation rate of 99.8% for Germany - https://www.epo.org/about-us/annual-reports-statistics/annual-report/2018/statistics/granted-patents.html#tab3

Figure 3 provides a breakdown of AI patent applications published in each of the IP5 offices, the World Intellectual Property Organization (WIPO), and the Vancouver Group countries[29]. Figure 3 shows that the recent increase in patenting activity seen in Figure 1 is largely driven by patents from China and the US. Although the US has the largest total number of AI patent applications, the recent growth in China is greater and the yearly figure has overtaken the US since 2014. However, China is distinct from other countries in that the majority of Chinese patent applications are published solely in China; only 19% of applications first filed in China have equivalent applications (family members) in other countries. For the US, there is more of a balance (53%), whereas for the UK, the reverse is true; the majority of GB patent applications (88%) first filed in the UK do have equivalents (family members) elsewhere[30]. A higher percentage, as seen with GB patent applications in this instance, may reflect the geographical size of the UK compared to other countries, and therefore a policy of UK-based applicants pursuing larger markets that are available outside the UK. China compared to the UK, on the other hand, is relatively self-contained in terms of its AI-related patenting activity, which may suggest that the applicants are satisfied with the market size found there.

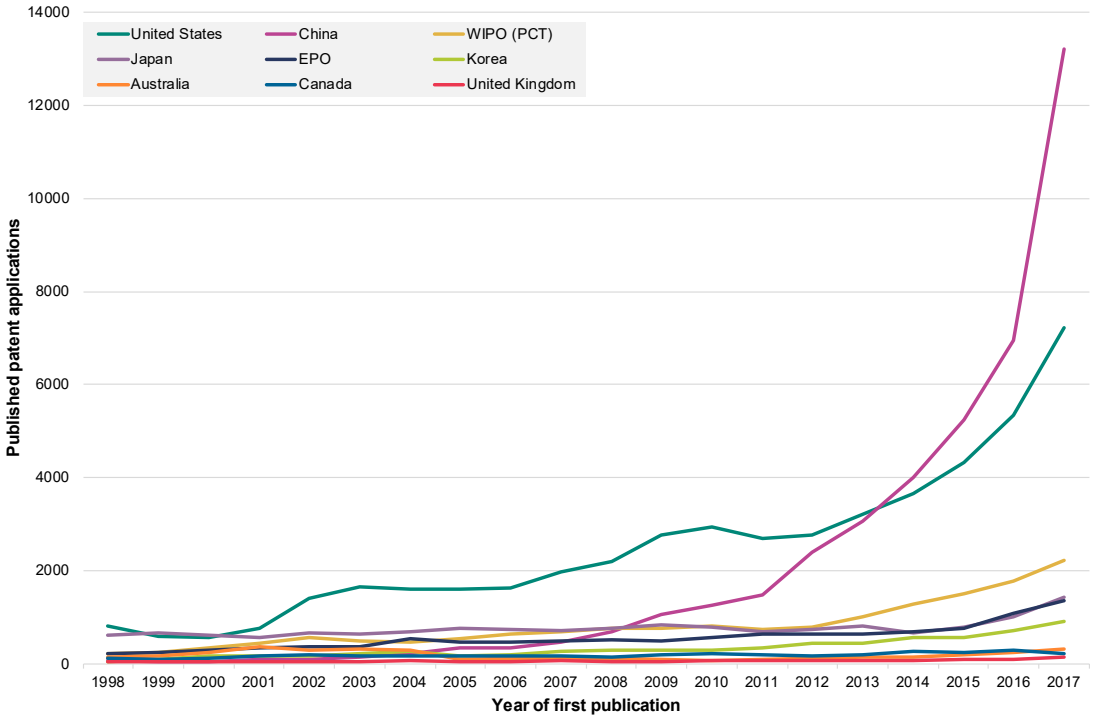

Figure 3: AI patent applications, per year of first publication, per publication country (Vancouver Group and IP5 countries, plus WIPO (PCT) applications)

29 The Vancouver Group is a forum of three IP offices comprising the IPO of the UK, the Canadian IP Office (CIPO) and IP Australia

30 See Appendix 8 for further details

Figure 4 shows the number of patent applications seeking protection in each of the Vancouver Group countries. Direct comparison of national patent applications is difficult because most EP patent applications have effect in the UK and most applicants obtain UK protection via the EPO route[31]. The sum of GB and EP patents is therefore plotted to give an indication of total AI patent coverage in the UK. From Figure 4 it can be seen that in general there is an increasing number of AI patent applications seeking protection in each jurisdiction.

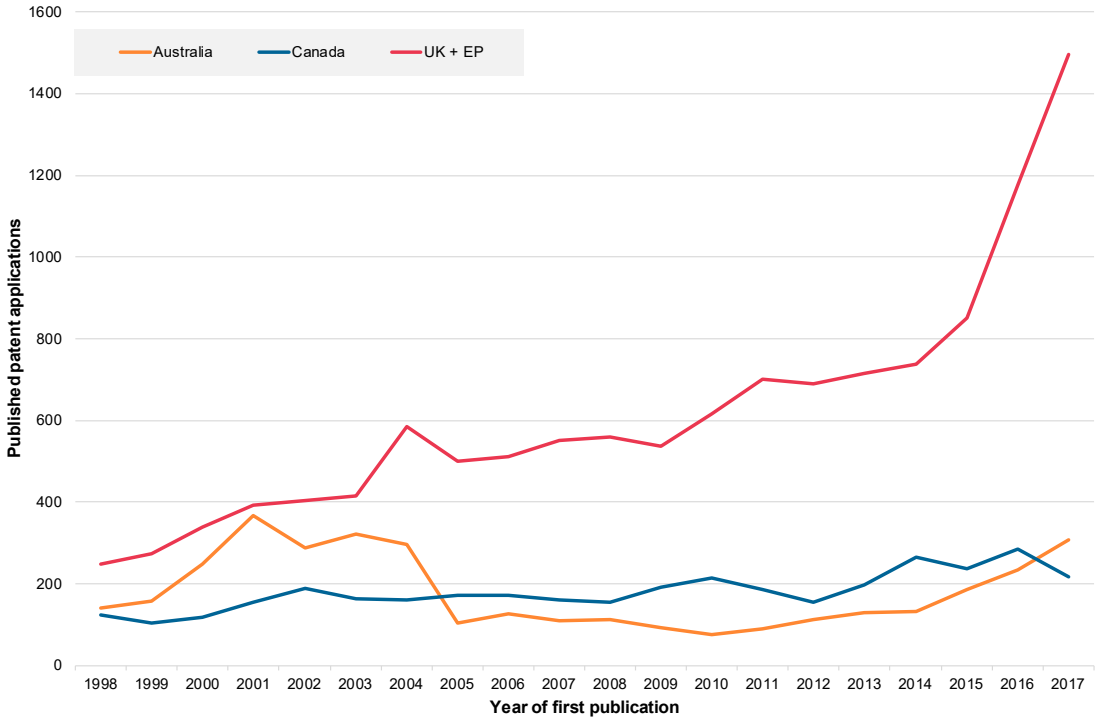

Figure 4: AI patent applications, per year of first publication, in each of the Vancouver Group countries

31 EP patent applications have a designation rate of 99.1% for the UK - https://www.epo.org/about-us/annual-reports-statistics/annual-report/2018/statistics/granted-patents.html#tab3

Although the previous charts show the general trend in the absolute number of patent applications received by each jurisdiction in the field of AI, it is also useful to consider this activity in the context of overall patenting activity in each of the IP offices, which has generally increased year-on-year. Figure 5 depicts the proportion of this activity that relates specifically to AI-related technologies. The proportions are small, but this simply reflects the vast range of technology areas for which patents are sought. The general worldwide trend is that AI-related technologies account for an increasing proportion of patents filed, reflecting the increasing prevalence that AI has in developing technologies. The countries shown generally follow this trend. Recently, the USA, UK and Australia have shown the most rapid increase in the proportion of their patenting activity that relates to AI. The US Patent and Trademark Office (USPTO) recently released guidance[32] relating to patenting abstract ideas, while the EPO also published[33] guidance relating specifically to patenting AI technology. The IPO of Singapore (IPOS), not shown in Figure 5, also recently announced that they will cut processing time for AI patent applications down from two years to six months[34]. These initiatives indicate the potential growth to come in the AI industry.

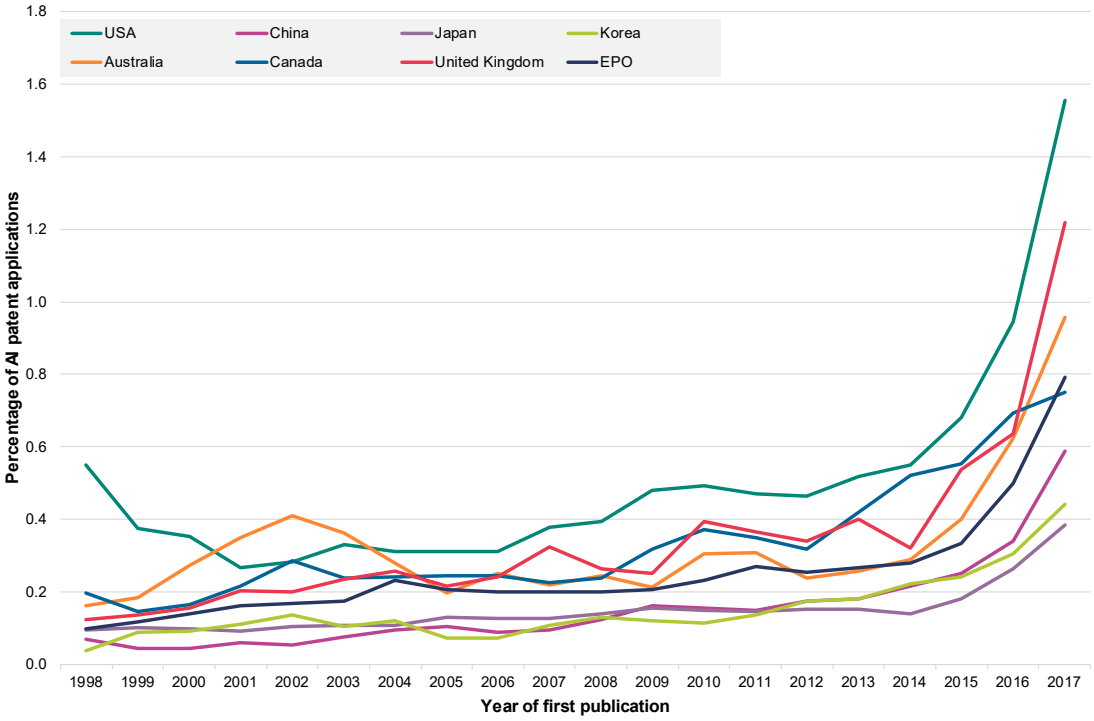

Figure 5: AI patent applications as a proportion of overall patenting activity, per publication country, per year of first publication (Vancouver Group and IP5 offices)

32 https://www.govinfo.gov/content/pkg/FR-2019-01-07/pdf/2018-28282.pdf - the USPTO does not explicitly tailor its new guidance to AI but the revised guidance may, in many cases, be applied to claims within this field

33 https://www.epo.org/law-practice/legal-texts/html/guidelines2018/e/g_ii_3_3_1.htm

34 https://sbr.com.sg/information-technology/news/ipos-cuts-patenting-process-time-ai-inventions

Top applicants worldwide

Figure 6 shows the leading patent applicants in terms of the number of AI patent families filed between 1998 and 2017, which includes IBM, Microsoft, Google, and other software companies[35]. There are also many manufacturing and consumer electronics firms, such as Toshiba, Samsung, and Sony. Most of these organisations are based in the US, Korea, Japan and China, reflecting the trends of country information seen in Figure 2. Siemens stands out as it is a German company.

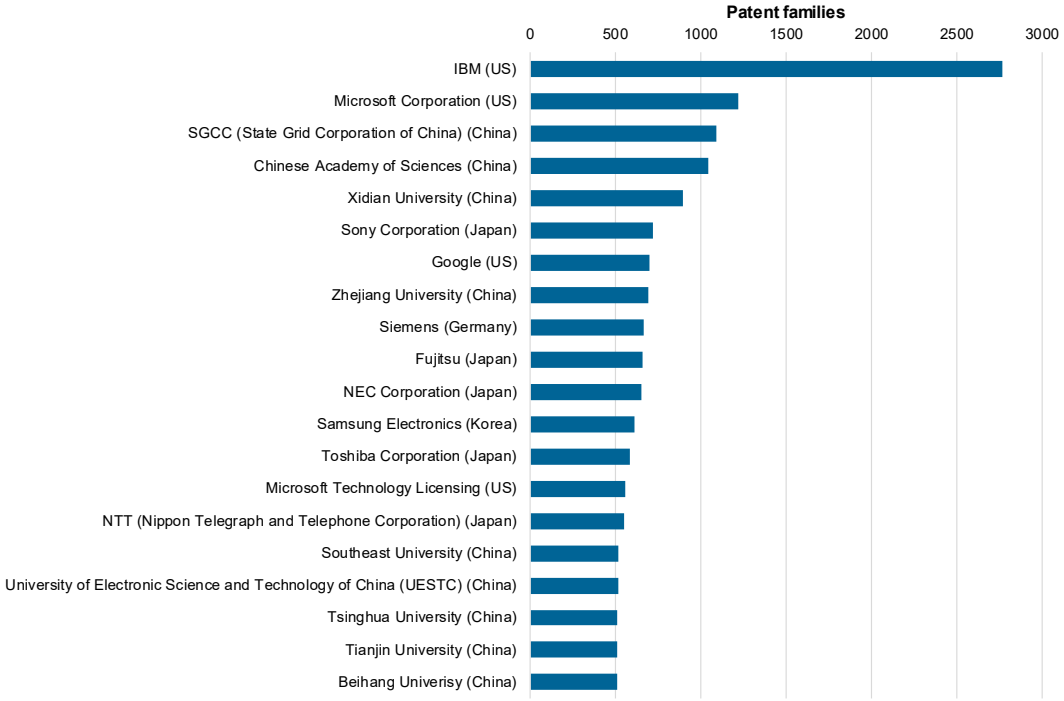

Figure 6: Top applicants by total number of AI patent families, 1998-2017

35 Microsoft Corporation and Microsoft Technology Licensing (MTL) are separate entities according to the PATSTAT Standardised Name field, and additional name cleaning has not been performed for this study. MTL own the vast majority of patents formerly owned by Microsoft Corporation and have therefore been deliberately kept separate

Geography of applicants and inventors

The jurisdiction of a patent application corresponds to where the patent is protected if the patent is granted. Filing behaviours may therefore be influenced by commercial considerations such as the size of market available in each country. The PATSTAT database contains the self-reported residency data of applicants and inventors associated with a patent. This data is used here to estimate the extent to which patenting activity is taking place within each country. Figure 7 shows the number of patent families, published between 1998 and 2017, which have an applicant or inventor in each of the countries shown. The majority of inventors are from the US with significantly fewer in other countries[36]. Country rankings remain the same if applicants and inventors are plotted separately so Figure 7 combines applicants and inventors together for conciseness.

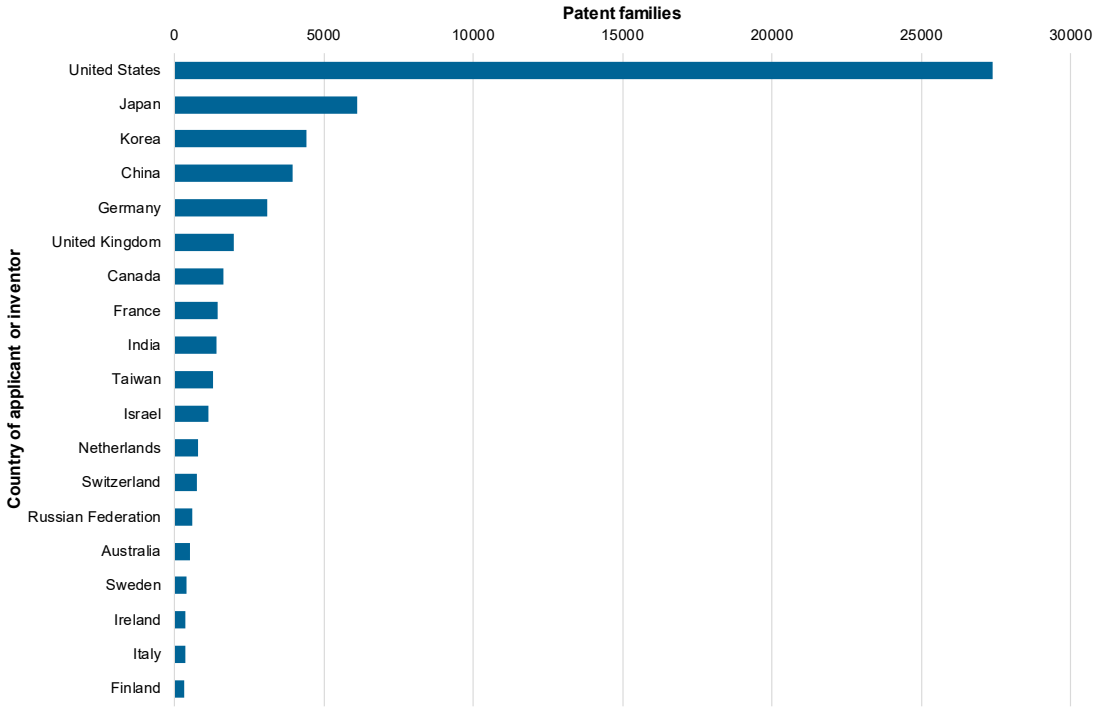

Figure 7: Top applicant/inventor countries for AI patent families, 1998-2017

Germany is ranked fifth worldwide in terms of applicant and inventor location. According to a study[37] from Institut der deutschen Wirtschaft Köln (Cologne Institute for Economic Research), 52% of globally registered patents[38] for autonomous driving, from 2010 to 2017, came from German companies. UK applicants and inventors are ranked sixth worldwide, which compares favourably to similar measures shown in other technology areas[39], and this is suggestive of an increasing UK presence in the growing field of AI.

36 Note that the number for China is significantly underestimated because of inconsistent coverage for applicant and inventor information for Chinese patents in the PATSTAT database

37 https://www.iwkoeln.de/studien/iw-kurzberichte/beitrag/hubertus-bardt-deutschland-haelt-fuehrungsrolle-bei-patenten-fuer-autonome-autos-356331.html

38 The study used the World Intellectual Property Organization's (WIPO) PATENTSCOPE database of PCT patents, while this report looks at data from the EPO's worldwide PATSTAT database

39 A selection of patent landscape overviews across a range of other technology areas can be found at https://www.gov.uk/government/collections/intellectual-property-research-patents

Relative Specialisation Index

Figure 8 plots a time series of the Relative Specialisation Index (RSI) for a selection of countries. The RSI is a measure that is calculated to account for the fact that some jurisdictions generally receive more patent applications than others regardless of technology area. It is designed to indicate the extent to which a country specialises in a particular technology area, compared to the worldwide average. A country is assumed to have contributed to an invention if one or more of the inventors or applicants is associated with that country. The extent of AI specialisation of a country is estimated using the proportion of its patent families in the dataset. More details are provided in Appendix 7.

Figure 8 includes all countries for which the RSI[40] is higher than Germany. For maximum clarity, rather than showing data for the 20-year period used throughout the rest of the report, Figure 8 only covers the time period between 2003 and 2017 . The use of the RSI means that countries with lower overall patenting activity are featured. It shows that the UK has the eighth highest RSI over the past 10 years and it will be interesting to see if the most recent upward trend continues. The USA shows a much higher RSI than other jurisdictions, which reflects that AI-related patents represent a greater proportion of patenting activity in the US. The laws surrounding the patentability of computer programs also differ between countries[41] and may result in the US seeing more patent applications in the software-dominated field of AI.

40 RSI for China is susceptible to error in light of inconsistent PATSTAT country coverage for Chinese patents, as noted previously

41 https://www.wipo.int/sme/en/documents/software_patents_fulltext.html

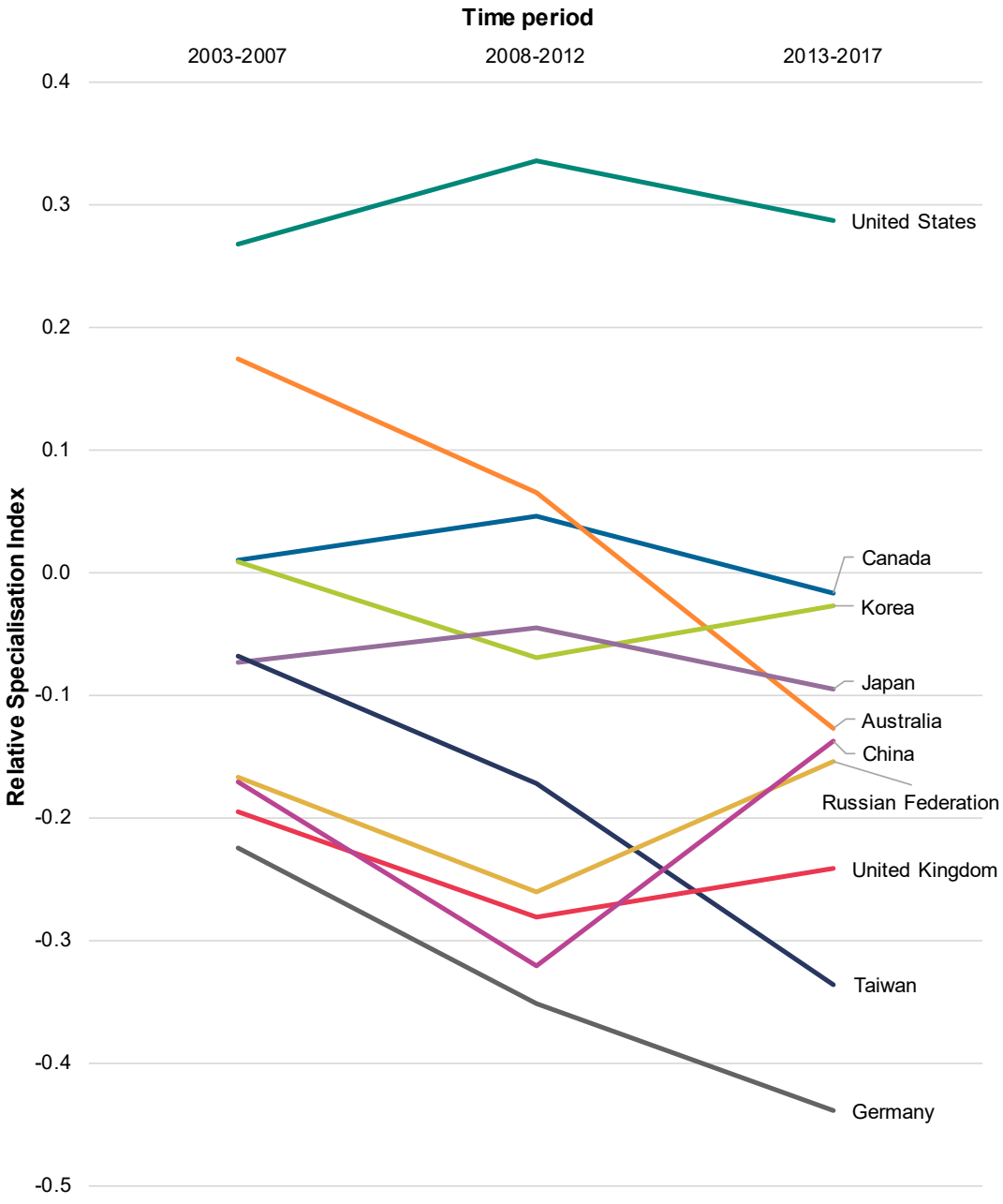

Figure 8: Relative Specialisation Index for AI patenting in select countries, 1998-2017

Trends in AI techniques

Figure 9 shows the growth in patenting activity in the development of various AI techniques[42]. Machine learning is a wide-ranging area; the faint bars to the right of the bold bars for that technique show how machine learning patents fall within various sub-categories. All of the areas shown have exhibited growth over the past 20 years, particularly over the past five years. Of the wide-ranging techniques associated with machine learning, neural networks have been associated with the largest amount of patenting activity, followed by other biology-inspired techniques, which include genetic algorithms and particle-swarm optimisation.

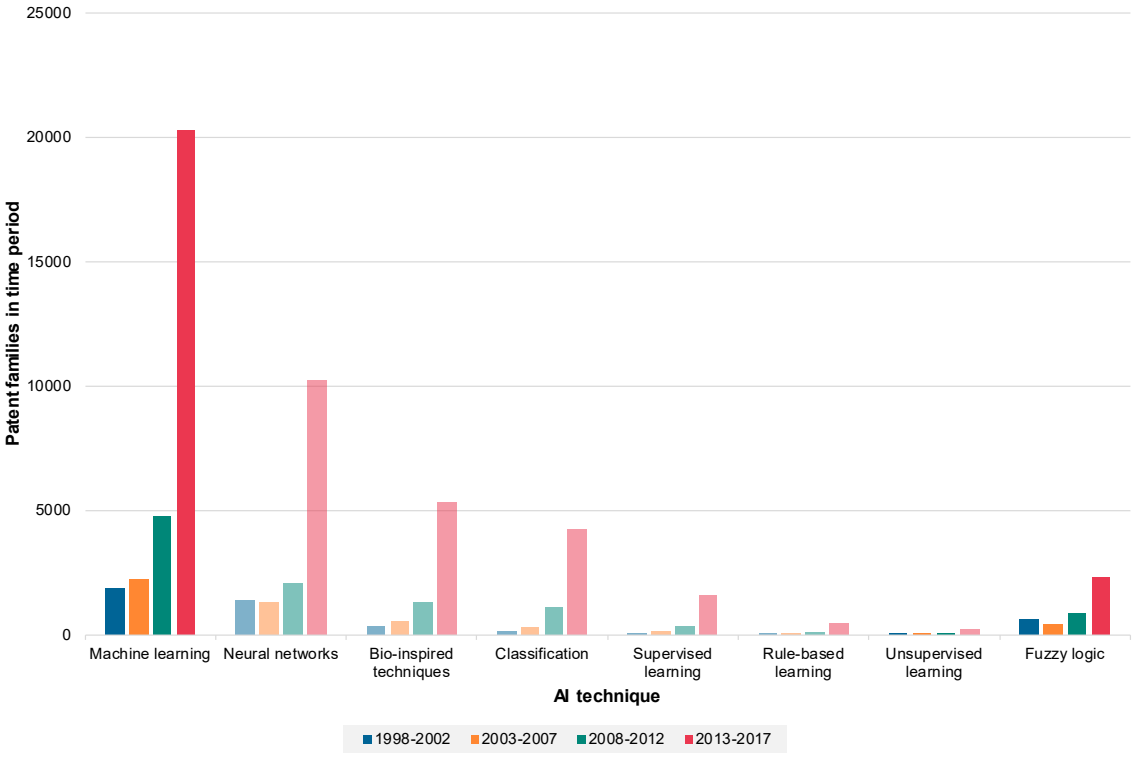

Figure 9: Patenting trends by type of AI technique

42 See Appendix 5 for details of how patents were associated with AI techniques

The UK patent landscape

UK applicants

This part of the report uses a subset of the dataset that includes AI patent applications published by any IP office in the world, for which PATSTAT has recorded an applicant or inventor with a GB country code.

There are 1970 patent families in this subset, comprising 5235 patent applications. This is a larger subset than that of GB patent applications, i.e. applications filed at the IPO of the UK. Note, however, that 1482 of the 1970 patent families in the subset used here include either a GB publication, an EP publication from the EPO, or a WO (PCT) publication from the World Intellectual Property Organization (WIPO), and therefore UK coverage is included for most, but not all, of these families[43]. This data shows that the reach of the UK's patenting activity is much greater than appears from looking only at GB patent applications (of which there are 1181 in the full dataset).

Figure 10 shows the countries in which UK-based inventors and applicants have filed applications, ranked by the total number of applications in each country. This shows that US coverage is highly sought after by UK-based applicants and inventors, perhaps because of US-based firms with employees in the UK (e.g. IBM has R&D centres in the UK) or collaborations between UK-based applicants and US-based firms. This could also reflect the dominant position of the US in the field of AI patents worlwide, as shown previously. It could also reflect the different laws in the US compared to the UK in terms of the patentability of computer programs[44], which is of particular importance in the software-dominated field of AI. Figure 10 shows that UK and EP coverage is also significant for UK-based applicants and inventors, as would be expected given that these routes provide patent protection in the UK but, even when taking the sum of GB and EP patents, the US still accounts for a larger share of the total.

This contrasts with China, which, although having significant levels of published AI patents, does not have as many patents from UK-based applicants and inventors; this is an area that might benefit from further investigation given that China is the world leader for total patent filings worldwide across all technologies[45] with more annual patent applications than the US, Japan, Korea and EPO combined.

43 EP patent applications have a designation rate of 99.1% for the UK - https://www.epo.org/about-us/annual-reports-statistics/annual-report/2018/statistics/granted-patents.html#tab3
44 https://www.wipo.int/sme/en/documents/software_patents_fulltext.html
45 https://www.wipo.int/edocs/pubdocs/en/wipo_pub_941_2018.pdf

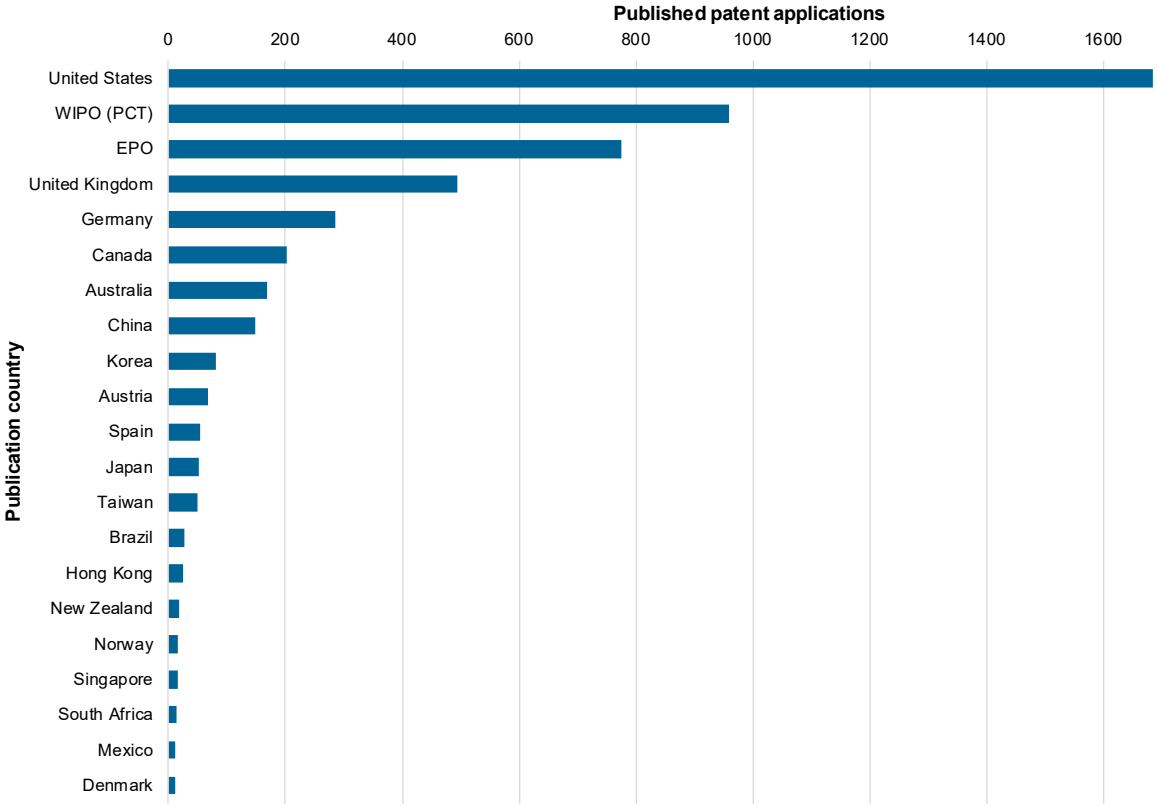

Figure 10: AI patent applications by publication country, with a UK-based applicant or inventor, 1998-2017

The trend over the last 20 years of UK-based applicants and inventors in AI-related technologies is shown in Figure 11. It largely follows the trend seen worldwide in Figure 1, in that there is a general increase that has accelerated notably in recent years.

Figure 12 shows the leading UK-based applicants[46]. BT Group is the top applicant with 86 AI patent families. BT publish in the US, Germany, Canada, Australia, China, and many other countries. BT obtains UK protection predominantly through the EPO route rather than via the IPO of the UK. IBM and GE Aviation Systems, which are among the market leaders worldwide, have a presence in this list by virtue of their UK-based subsidiaries, but BT still dominates in this UK data subset.

For each of the leading UK applicants, Figure 12 also shows the percentage of AI patent families (i.e. patent families in the present data set) compared with the total number of patent families in their name (i.e. their overall patent portfolio) between 1998 and 2017. This gives an indication of the degree of AI specialisation of the companies, with the general pattern being that smaller companies have a higher percentage, whereas larger companies tend to be more diversified.

46 Note that 'University of London' patents belong primarily to King's College London and University College London (UCL)

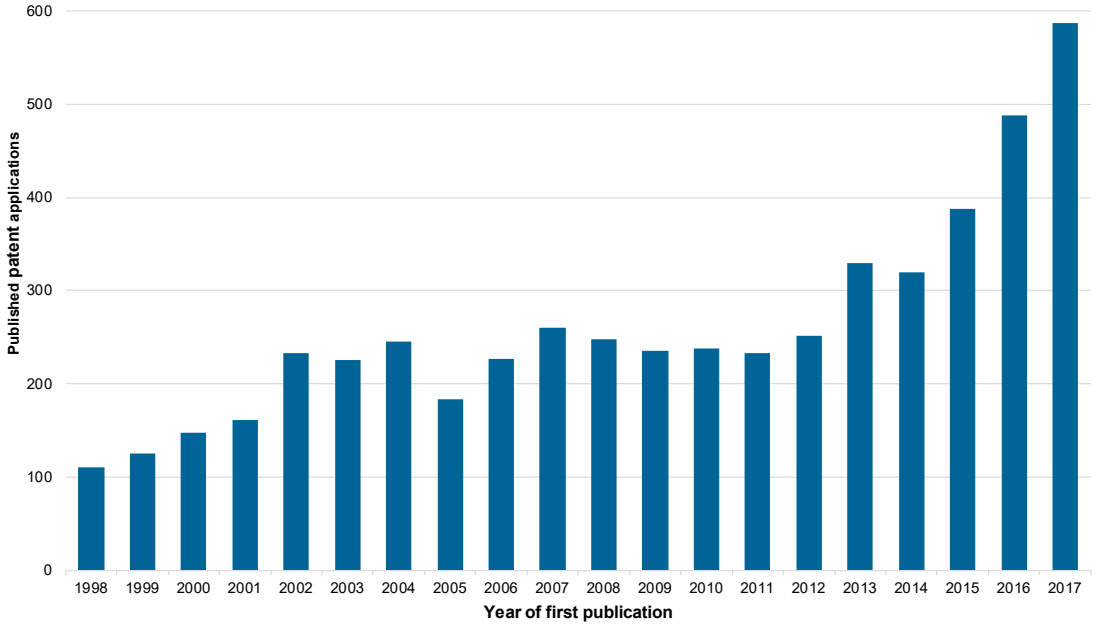

Figure 11: AI patent applications by year of first publication for UK-based applicants and inventors

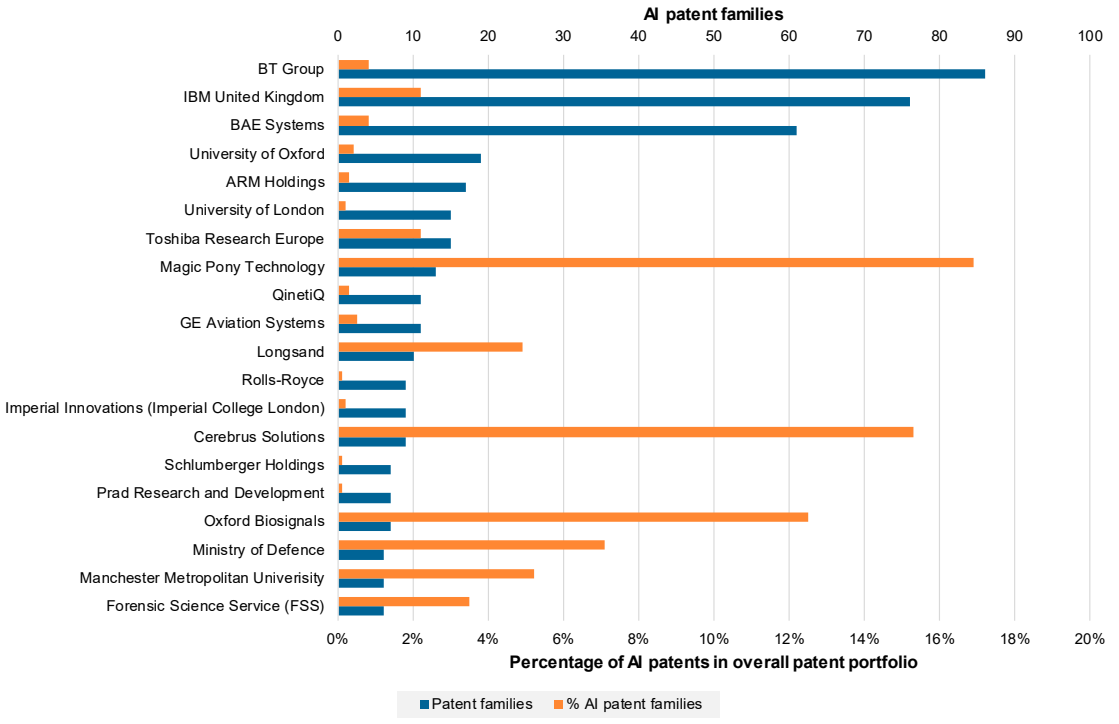

Figure 12: Top UK-based applicants and proportion of their overall patent portfolio that relates to AI, 1998-2017

London-based AI start-up Magic Pony Technology was acquired[47] by Twitter for $102million in 2016

Case Study: BT

BT Group Plc[48] is the most prolific applicant from the UK for filing AI patents. It has roots going back to Britain's first telecommunications company, the Electric Telegraph Company, although the BT (British Telecom) name dates from 1981 when the British Telecommunications Act was passed. This transferred the state-owned telephone network from the Post Office to a new statutory corporation, British Telecommunications, branded as British Telecom[49].

BT operates worldwide, and this is reflected in the patent data as the majority of BT's patent applications are WIPO (PCT) applications and EPO applications. They also have a significant number of applications in the US, Germany, Canada, Australia, and China, with smaller numbers of patents in other countries. Limited evidence was found of significant collaboration between BT and other companies in applying for patents together as co-applicants. Many applications relate to obvious telecommunications matters such as routing and security in networks, whilst some reach into computational topics. Some examples of the breadth of topics covered by BT's patent portfolio are shown below.

- Speech analysis using neural networks, for example to assess the quality of equipment, or to identify and eliminate noise (EP 0846318 and EP 0840975).
- Optimising the allocation of network resources in a cloud-based network (WO 2016/107725).
- Generating recommendations of digital content (e.g. music) to a user based on the user profile (WO 2016/207308), and further applications relating to training of recommender systems.
- Training a neural network to identify malware being transmitted through a network (WO 2016/146609)
- Pattern matching algorithm for use in machine learning problems. This application is quite theoretical in nature and has no explicit application in the telecommunications field (WO 2015/097429).
- Text classifier for online content generated within social networking sites (EP 2369505).

47 https://www.wired.co.uk/article/entrepreneur-first-startups-london
48 https://www.bt.com/
49 https://www.btplc.com/Thegroup/BTsHistory/Eventsintelecommunicationshistory/index.htm

Figure 13 shows how changes to the patent portfolio size of UK-based applicants has changed over time. Patent portfolio size refers to the total number of published AI-related patent applications for each applicant. It can be seen that a majority of UK-based patent applicants at any given time over the 20 year period have a portfolio size of 1, although the proportion has reduced over time. Portfolio sizes of 2-5 patent applications have grown significantly. Portfolio sizes of more than 5 are rare among UK-based applicants. The increasing portfolio sizes suggests that AI patent applicants will go on to file further patent applications and, hence, that the same players stay in the field. Figure 13 also shows that the majority of AI-related patents are from those with few patent applications, suggesting smaller and newer applicants account for a large proportion of patenting activity in the AI sector within the UK.

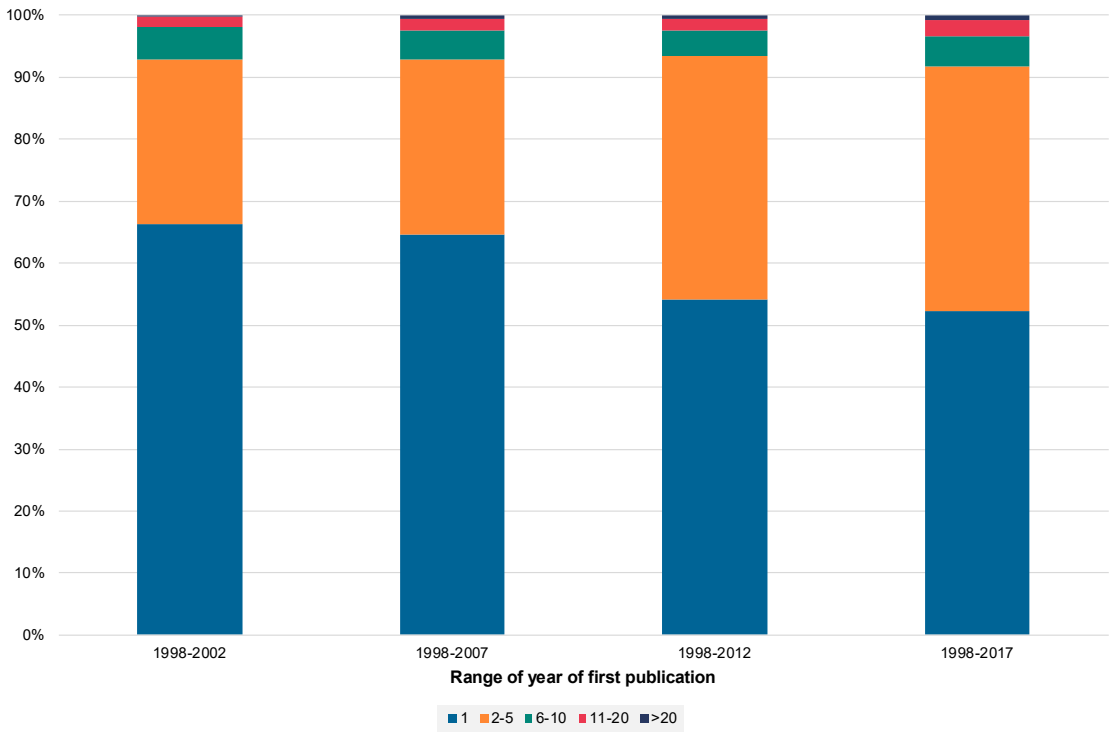

Figure 13: AI patent portfolio size progression over time for UK-based applicants

GB patents

This section of the report uses a subset of the dataset that includes AI patent applications published by the IPO of the UK which were made by applicants or inventors from anywhere in the world. It includes 1181 patent applications and 1131 patent families. Note that it is not common for a patent family to have more than one GB patent application, and so most of the patent families in this subset correspond to a single GB patent application. It is notable that this subset is smaller than the subset of UK-based applicants and inventors.

Figure 14 shows the trend of AI-related patents published by the IPO of the UK over the last two decades; this also largely follows the global trend of applications, although there are slightly more dips in UK-published applications in the last 10 years.

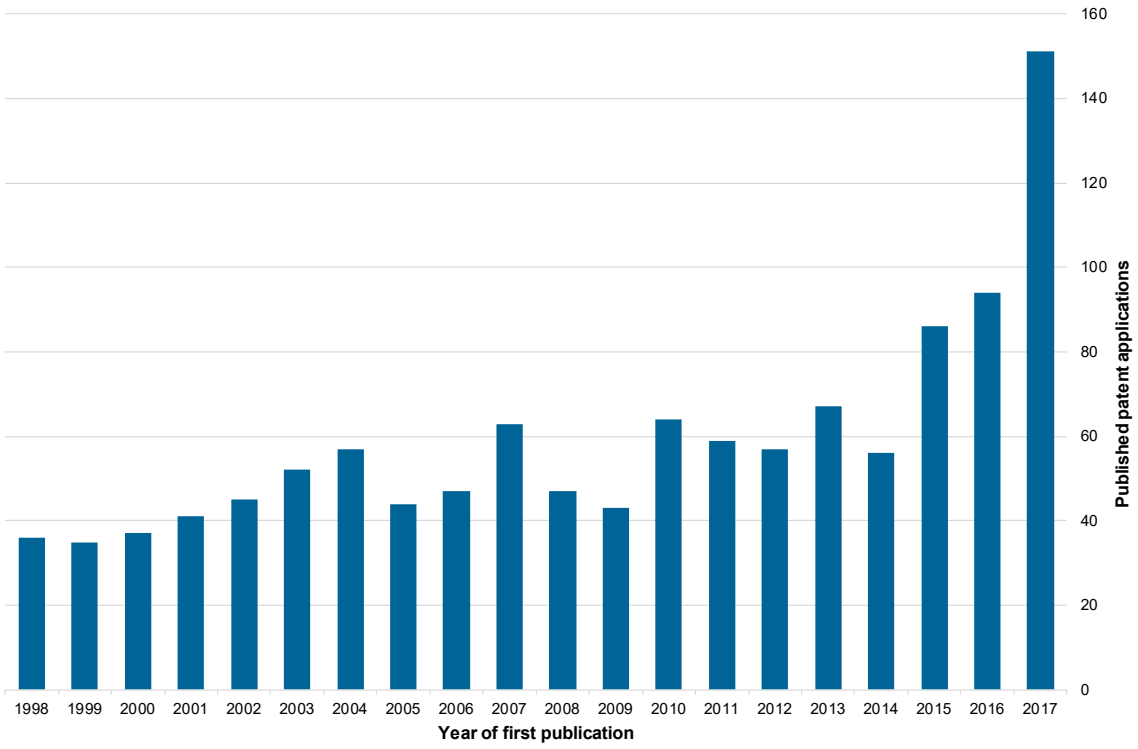

Figure 14: AI patent applications published by the IPO of the UK, by year of first publication

The top applicant and inventor countries for AI patents published by the IPO of the UK is shown in Figure 15. This chart shows that more AI-related patent applications are made by US-based applicants and inventors than UK ones. This is likely a reflection of the fact that many of the leading applicants worldwide are US-based technology companies (as shown in Figure 6 and 7), but it is still striking. Note this dataset takes no account of applications made to the EPO, and that EP patents make up most of the patents which are in force in the UK.

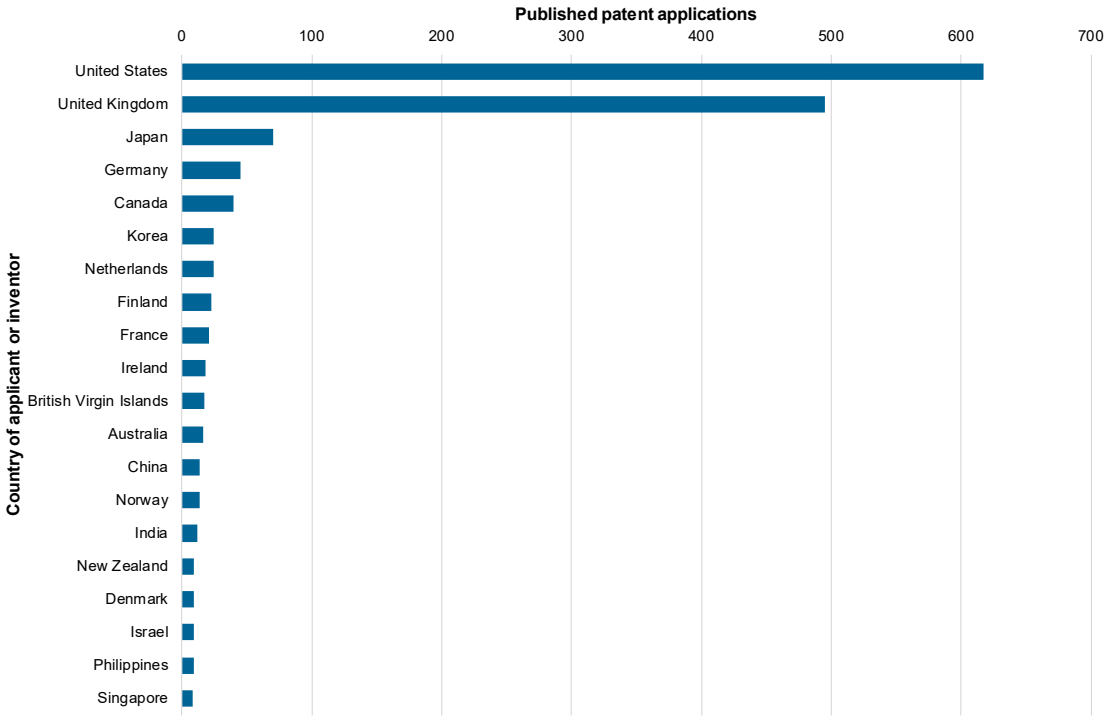

Figure 15: Applicant and inventor country information for AI patent applications published by the IPO of the UK, 1998-2017

The data for AI-related patents filed via the EPO route (not shown here) displays a similar degree of dominance by the US, but with a significant contribution from Germany and Japan. The UK and France each have a similar level of contribution to EP patent applications. When looking in detail at the individual applicants among the EP patent applications, Siemens is the most prolific applicant. BT is in eleventh place, reflecting its preference for protection via the EPO rather the IPO of the UK, as noted previously. Many large companies from the US and elsewhere are also present. GB patent applications are therefore not merely a microcosm of EP patent applications, and certain companies seem to prefer protection in the UK via the domestic national route at the IPO of the UK rather than via the EPO route. This choice can be made for a number of reasons; for example, in some specialised industries, and in particularly the oil industry, coverage is required only in selected countries whereas, in other cases, the GB patent application may be used to obtain a relatively quick search and opinion of patentability.

Figure 16 shows the applicants publishing the most AI patents through the IPO of the UK over the last two decades. This list differs from that of the UK-based applicants and inventors dataset explored in Figure 12, and the presence of companies in the oil industry such as Baker Hughes, Halliburton, and Schlumberger, suggest that they may specifically target the UK for protection.

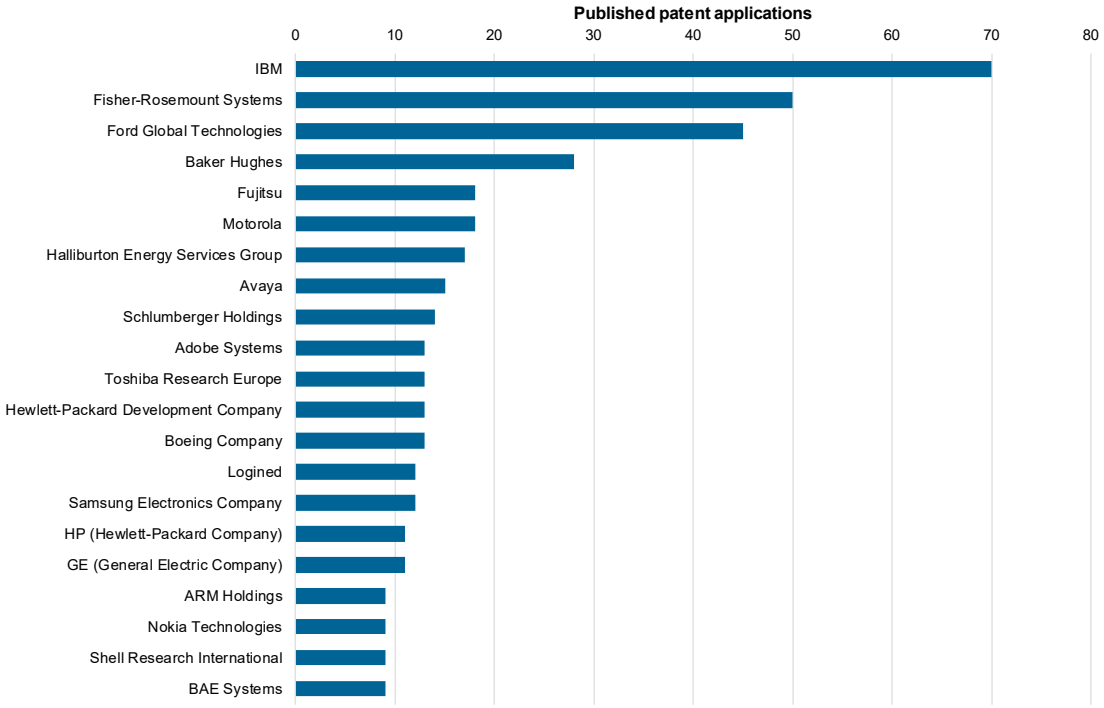

Figure 16: Top applicants for AI patent applications published by the IPO of the UK, 1998-2017

A British smartphone app, SwiftKey, uses AI to predict words a user wants to write and was bought[50] by Microsoft for £174million in 2016

50 https://www.telegraph.co.uk/technology/2016/02/03/swiftkeys-british-founders-made-millionaires-after-microsoft-buy/

Industry trends

Figure 17 shows the main application areas of AI patent families worldwide. In 2008 WIPO defined[51] five technology sectors, subdivided into 35 broad technology fields, to categorise all patents depending on where they are classified under the International Patent Classification (IPC) Scheme[52]. A similar approach[53] is adopted here although the 'Computer technology' area used by WIPO is further subdivided because it includes a range of differing application areas of AI. For readability, application areas which include very few AI-related patents have also been aggregated. The bold bars correspond to WIPO technology sectors, and a further sub-division of these sectors is provided below each of them using faint bars to show the WIPO technology fields. A similar chart for UK-based applicant and inventors is shown in Figure 18.

In both charts and for each time period, when added together the total length of the bars is greater than 100%; the reason is that any patent family that spans multiple application areas is counted multiple times. Figure 17 suggests a general trend away from patents that span multiple application areas. The average number of application areas per patent family falls from 1.8 to 1.5 between 2003 and 2017; this is perhaps a reflection that developments in AI are becoming more incremental and, hence, more specific to particular application areas.

Figure 18 shows that speech recognition and audio-visual technology has accounted for an increasing proportion of AI patenting activity by UK-based applicants and inventors; this contrasts with the downward trend shown globally. The UK follows the global trend in electrical engineering areas for AI, but there are particularly sharp increases in telecommunications and image processing. Mechanical engineering has remained steady in the worldwide market in recent years, but this is an area that is growing in the UK and may be driven by developments in applying AI to transport. Transport accounts for a higher proportion of AI-related patents globally, but the UK shows a higher proportional increase in recent years; this could be attributed to the growing industry for autonomous vehicles in the UK. It should also be noted that autonomous vehicles rely on a wide range of technologies, such as measurement (using sensors), control, image processing, and recognition of data; patents with applications in autonomous vehicles may therefore be distributed across these application areas rather than residing only in the transport category.

51 See https://www.wipo.int/export/sites/www/ipstats/en/statistics/patents/pdf/wipo_ipc_technology.pdf for the methodology used

52 The WIPO IPC-Technology Concordance table is available at https://www.wipo.int/ipstats/en/index.html

53 See Appendix 4 for further details

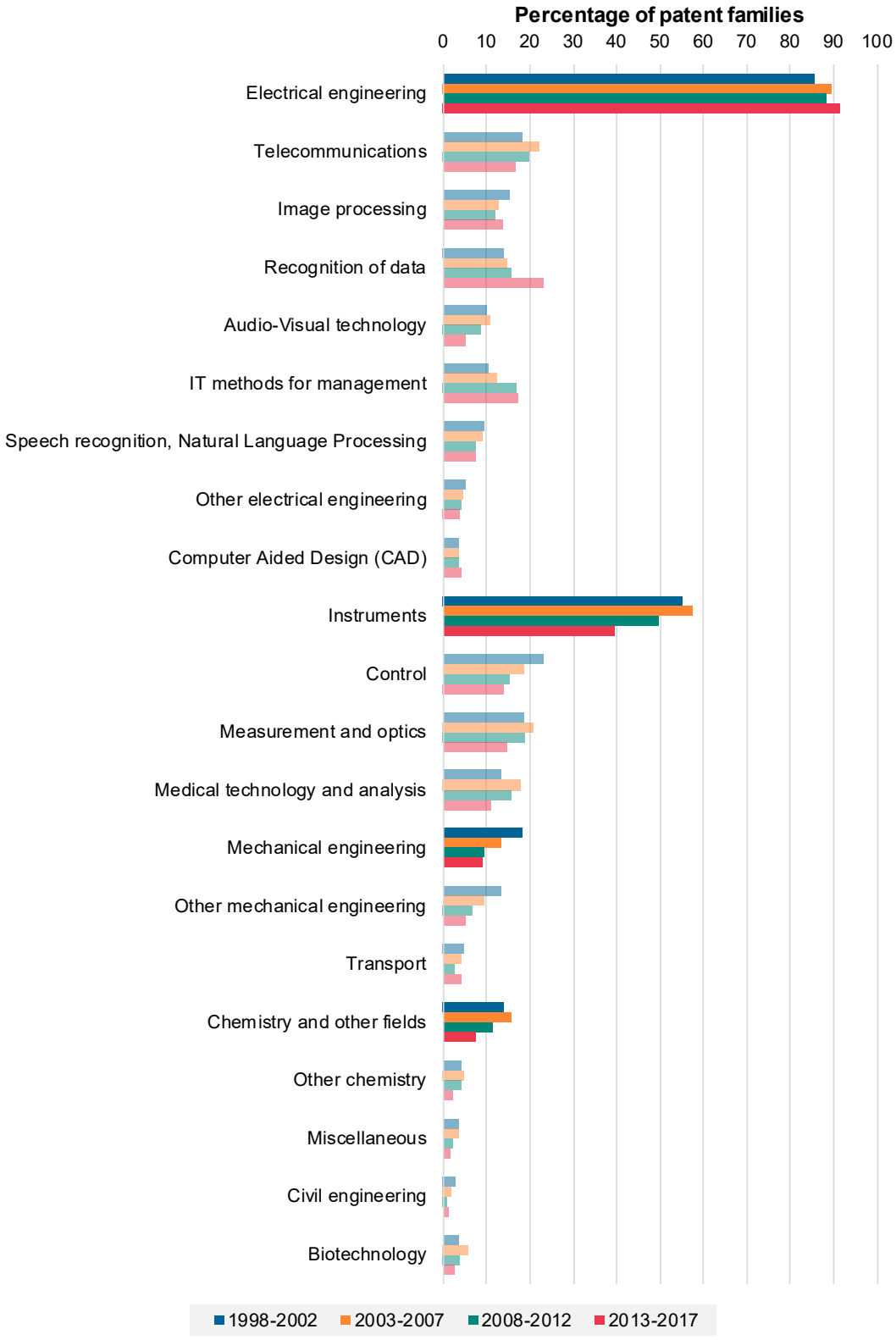

Figure 17: Time series of application areas of AI patent families worldwide. Bold bars relate to WIPO technology sectors and faint bars sub-divide these into WIPO technology fields

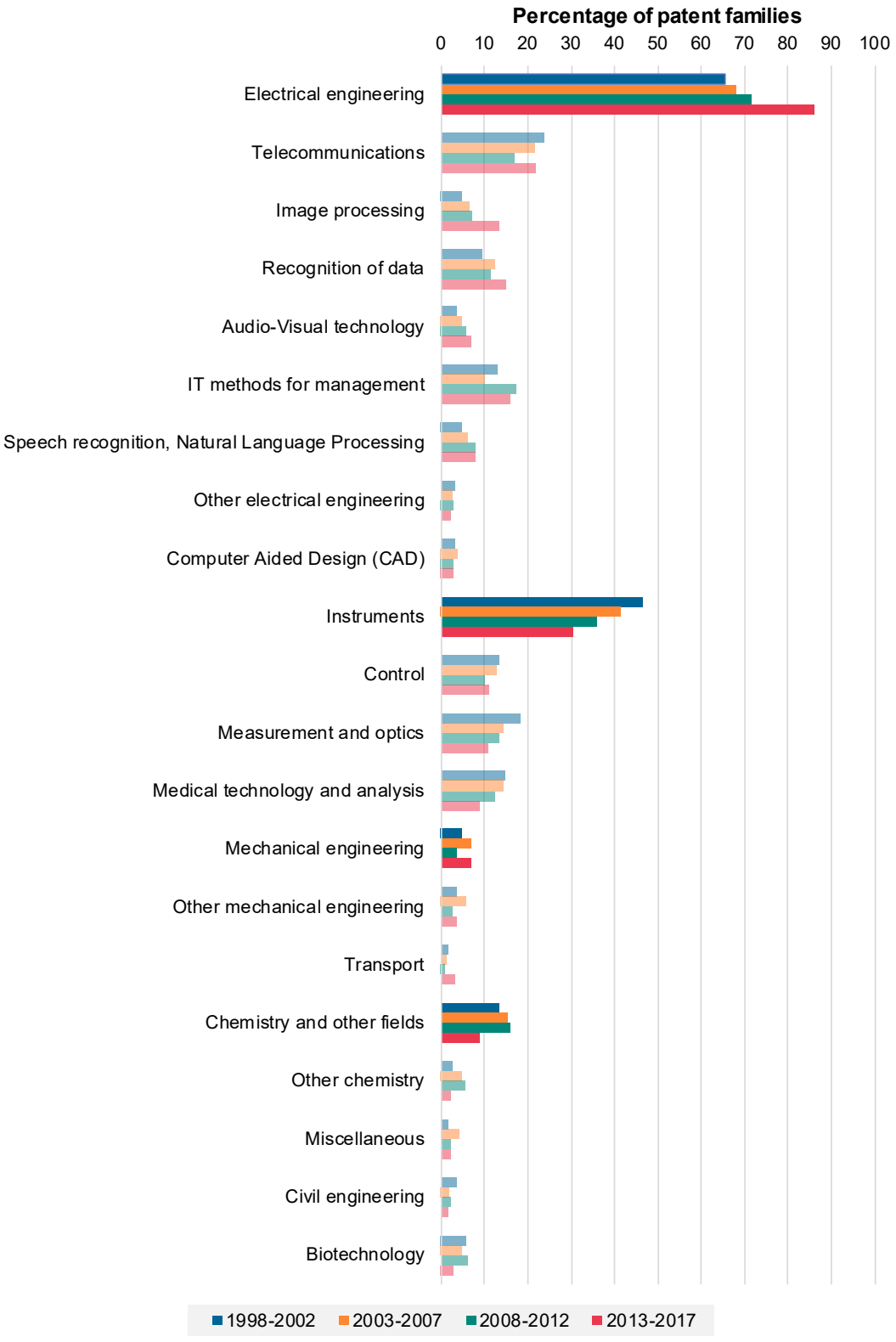

Figure 18: Time series of application areas of AI patent families with a UK-based applicant or inventor. Bold bars relate to WIPO technology sectors and faint bars sub-divide these into WIPO technology fields

Case Study: Audio Analytic

Audio Analytic[54] is a UK-based company that works in sound recognition. It was founded in 2010 by Christopher Mitchell. Audio Analytic have developed a neural network that is optimised for sound data, and have released ai3, which is licensed by their customers to give consumer products a sense of hearing[55] by recognising sound types such as a breaking window or a car alarm.

Some of their patents relate to the applications of AI towards sound recognition, and are described below:

WO 2010/070314 describes a method of modelling background noise, which enables unusual sounds to be identified more reliably. For example, detection of a car window being broken is done more reliably by using a model of background traffic noise.

GB 2534027 relates to the use of sound model to detect a type of sound. Conventionally, audio data is transmitted to the cloud for processing, but this patent involves transmitting a sample sound to the cloud, receiving a sound model from the cloud, and storing it on the user device for future use. This avoids the need to transmit data to the cloud since sound processing can then be done by the user device.

Audio Analytic have many applications for their technology, such as driver assistance in vehicles, security and safety monitoring in the home, or in smart speakers. They have also partnered with a wide variety of companies with a view towards developing products for the smart home and for developing smart microphones.

54 https://www.audioanalytic.com/
55 https://www.cambridgeindependent.co.uk/business/audio-analytic-the-shazam-of-real-world-sounds-9053022/

UK collaborations

In the dataset used in this report, many patents were found for which multiple organisations are listed as co-applicants. This implies that ownership was shared between those organisations and, hence, that the invention arose out of some collaborative activity between the organisations. UK-based collaboration relating to AI takes place in a wide variety of technological areas, as evidenced by the following examples of collaborative patenting activity:

- BAE Systems with University of Leicester - these inventions are for health management of a complex system, using neuro-fuzzy operations to simplify and assist decision making.

- BAE Systems with Rolls Royce - these inventions are about using a genetic programming algorithm to help assess large numbers of designs in a design space and choose an optimum design.

- King's College London with Guy's and St. Thomas NHS Foundation Trust, and with Cydar - these inventions relate to image analysis of medical images to intelligently align images from different types of scans.

- Queen Mary University of London with Broadchart International and British Broadcasting Corporation (BBC) - this invention relates to using machine learning to enable a system to choose music suitable for a particular mood.

- Queen Mary University of London with IESO Digital Health Company - this invention concerns analysing text messages to determine characteristics of the sender/receiver.

- Schlumberger Holdings with Prad Research and Development Company - several inventions have arisen through this collaboration, and some relate to data analysis including using a neural network to analyse and discern fluid components in chromatography data. Another invention relates to the autonomous estimation of the position of an apparatus in a borehole.

- Johnson Matthey with Eminox - this invention relates to controlling the nitrous oxides released by an internal combustion engine by controlling the rate of reductant injection.

Conclusions

Artificial Intelligence (AI) is a rapidly advancing area of technology and it is estimated that it will add £630bn to the UK economy alone by 2035. This study has shown an overview of the AI patent landscape, both worldwide and specifically to the UK. Adopting a relatively narrow approach in the search strategy resulted in a smaller dataset than other recent studies but ensured that data analysed was representative of core AI patenting activity whilst limiting the amount of possible noise (false positives) in the dataset.

Patenting activity, both in the UK and globally, has increased between 1998 and 2017, particularly in the recent years. In 2017, almost 30,000 global AI-related patent applications were published worldwide, which is twice as many as were published two years earlier in 2015. The UK AI sector has seen its patenting activity more than double in the past decade.

While the US and China remain key players in the AI patent landscape in terms of absolute numbers of applications, the proportion of AI patent applications in the UK is growing at a similar rate to that of the US. It is also shown that the vast majority (88%) of patents first filed in the UK are also protected abroad, reflecting the global nature of the AI sector and the desire for UK-based applicants and inventors to seek protection and commercialise their inventions in international markets. Key areas of AI patenting growth in the UK include transport, image processing and telecommunications.

This report provides the basis for further research into the growth of AI at both the global and UK level, touching on areas of significance and highlighting differences across global players. AI is increasingly becoming embedded into modern society and, in this rapidly growing sector, it is important to note the role that patents, and IP more generally, have to play in facilitating this growth as the technology continues to develop.

Appendices

Appendix 1. Data and methodology - patent search strategy

The search strategy taken in this report is deliberately narrow to ensure that the retrieved patents each have a high presumption of relating to AI. AI has applications in a broad range of technology areas; however, patents classified in those technology areas do not necessarily relate to AI. For example, speech recognition is a well-known application of AI technologies, but also involves conventional pre-processing steps such as decomposing sound into frequency bands.

Patents are classified under either the International Patent Classification (IPC) scheme or the Cooperative Patent Classification (CPC) scheme, according to the technology areas they relate to. The CPC scheme is more detailed than the IPC scheme, but the IPC scheme is more widely adopted worldwide. Part of the search strategy used is therefore to include all patents classified in any IPC or CPC area that relates specifically to AI (as opposed to possibly using AI). There are a relatively small number of these classification areas; there is a risk of omitting patents if those areas are relied on completely. To mitigate against this risk, patents were retrieved that include certain keywords in the abstract (which summarises the technical content of the patent). Again, a narrow approach was adopted towards the keywords used to ensure that the retrieved patents are each highly likely to relate to AI.

Table 1 contains marks used from the IPC scheme, Table 2 contains marks used from the CPC scheme and Table 3 contains the keywords used to search the abstract.

Table 1: Areas of the IPC scheme used by the search strategy					
G06F19/24	G06N3	G06N5	G06N7/02	G06N7/04	G06N7/06
G06N20	G06T1/40	G16B4/20	G16B4/30	G16C20/70	

Table 2: Areas of the CPC scheme used by the search strategy				
A61B5/7267	G01N33/0034	G06F19/24	G10H2250/151	H04L2025/03464
B29C66/965	G01N2201/1296	G06F19/707	G10H2250/311	H04N21/4662
B29C2945/76979	G01S7/417	G06F2207/4824	G10K2210/3024	H04N21/4663
B60G2600/1876	G05B13/027	G06K7/1482	G10K2210/3038	H04N21/4665

Table 2: Areas of the CPC scheme used by the search strategy				
B60G2600/1878	G05B13/0275	G06N3/004	G10L25/30	H04N21/4666
B60G2600/1879	G05B13/028	G06N3/02	G11B20/10518	H04Q2213/054
E21B2041/0028	G05B13/0285	G06N3/12	H01J2237/30427	H04Q2213/13343
F02D41/1405	G05B13/029	G06N5	H02P21/0014	H04Q2213/343
F03D7/046	G05B13/0295	G06N7	H02P23/0018	H04R25/507
F05B2270/707	G05B2219/33002	G06N20	H03H2017/0208	Y10S128/924
F05B2270/709	G05D1/0088	G06N99/005	H03H2222/04	Y10S128/925
F05D2270/707	G06F11/1476	G06T3/4046	H04L25/0254	Y10S706
F05D2270/709	G06F11/2257	G06T9/002	H04L25/03165	
F16H2061/0081	G06F11/2263	G06T2207/20081	H04L41/16	
F16H2061/0084	G06F15/18	G06T2207/20084	H04L45/08	
G01N29/4481	G06F17/16	G08B29/186	H04L2012/5686	

The hyphenated form of the keywords is shown in Table 3, where appropriate. Searching was done by first pre-processing the abstracts to replace hyphens with whitespace, and then matching for the whitespace-separated constituent parts. Asterisks denote wildcard operators, which match with any text. The effect is that, for example, 'back-propogat*' will retrieve patents whose abstracts contains phrases such as 'back-propagation' or 'back propagated'.

Table 3: Keywords used in the search strategy			
ant-colony	factorization machin*	high-dimensional* feature*	particle-swarm*
bee-colony	factorisation machin*	high-dimensional* input*	pattern-recogni*
fire-fly	feature engineer*	k-means	policy-gradient method
adversar* network*	feature extract*	kernel learn*	q-learn*
artificial*-intelligen*	feature select*	latent-variable*	random-forest*
association rule	fuzzy-c	link* predict*	recommender system*
auto-encod*	fuzzy environment*	machine intelligen*	reinforc* learn*
autonom* comput*	fuzzy logic*	machine learn*	sentiment* analy*
back-propagat*	fuzzy number*	map-reduce	sparse represent*
back-propogat*	fuzzy set*	memetic algorithm*	sparse*-code*
cognitiv* comput*	fuzzy system*	multi* label* classif*	spectral cluster*
collaborat* filter*	gaussian mixture model	multi*-objective* algorithm*	stochastic*-gradient*
deep-belief network*	gaussian process*	multi*-objective* optim*	*supervis* learn*
deep-learn*	genetic program*	natural-gradient	support-vector machine
differential*-evol* algorithm*	genetic* algorithm	neural-turing	swarm behav*
dimensional*-reduc*	high-dimensional* data	*neural-network*	swarm intell*
ensemble-learn*	high-dimensional* model*	neuro-morph comput*	transfer-learn*
evolution* algorithm*	high-dimensional* space*	non-negative matri* factor*	variation*-infer*
evolution* comput*	high-dimensional* system*	object-recogni*	vector-machine*

Methodology

PATSTAT is a widely used worldwide database of bibliographic patent information that is maintained by the European Patent Office (EPO). The version of PATSTAT used for this report was the Autumn 2018 Edition and includes records from July 2018 or earlier; this was the latest version of PATSTAT available at the time of writing and so patents published in 2018 or after have been excluded from the study. The dataset used therefore covers the 20 year period between 1998 and 2017. Due to time constraints, and to the number of patent abstracts held on PATSTAT, it was unfeasible to perform a keyword search of the abstract data held for all patents on PATSTAT. The approach taken was therefore to use LexisNexis PatentStrategies, a proprietary patent searching system, to retrieve a preliminary subset of patents using the search strategy detailed previously. PatentStrategies draws from several sources including DocDB, which is the EPO's underlying master database also used to extract each snapshot edition of PATSTAT; the set of patents retrieved using PatentStrategies is therefore expected to include any patent that would have been retrieved by querying PATSTAT directly. The preliminary set of patents was then reconciled against the information contained in PATSTAT by ensuring that all patents in the final dataset was either classified in one of the IPC or CPC areas in Table 1 or Table 2, or contained one of the keywords listed in Table 3 in its abstract.

Appendix 2. Data pre-processing

Invention patents

Documents were restricted to invention patents only. Utility models and other non-invention patents were removed by filtering the PATSTAT *ipr_type* field to PI.

Inventor and applicant information

Applicant and inventor names in the dataset are taken from the PATSTAT Standardised Name field (*psn_name*) in PATSTAT. This data is already cleaned to reduce the chance of a single person or company being counted separately because of spelling errors and variations. For example:

John Smith
JOHN SMITH
SMITH, JOHN
JOHN SMITH.

should be considered the same name. No further name cleaning has been done on this dataset.

Country information for applicants and inventors is based on the *person_ctry_code* field in PATSTAT, with further processing since the coverage of this information is not complete.

Country information was estimated for identical names that appear in the dataset on some occasions with a country code and on some occasions without a country code. A contrived example of this is shown below.

Application ID	Applicant or inventor name (psn_name)	Applicant or inventor country (person_ctry_code)
12345	JOHN SMITH	GB
12346	JOHN SMITH	GB
12347	JOHN SMITH	GB
12348	JOHN SMITH	
12349	JOHN SMITH	GB

In this situation, all occurrences of John Smith were assigned country code GB.

In cases where the name is found with more than one country code, the most common code is assigned. For example:

Application ID	Applicant or inventor name (psn_name)	Applicant or inventor country (person_ctry_code)
12345	JOHN SMITH	GB
12346	JOHN SMITH	GB
12347	JOHN SMITH	GB
12348	JOHN SMITH	
12349	JOHN SMITH	US

In this situation, the unassigned occurrence of John Smith is assigned country code GB on the basis it is the most likely value.

The exception to this is where blank values are more common, in which case no country is assigned.

Appendix 3. Dataset summary

Table 4 provides a summary of the dataset.

Table 4: Dataset summary

	Worldwide dataset	GB publications	UK applicant or inventor
Number of patent families	85,648	1131	1970
Number of patent applications	163,588	1181	5235
Publication year range	1998-2017	1998-2017	1998-2017

Appendix 4. Attribution of patents to application areas

Patents are classified under the IPC scheme according to the technology that they relate to. There are over 600 subclasses, each relating to various technology areas. In 2008, WIPO grouped these subclasses together into 35 technology fields, which are themselves grouped together into 5 technology sectors. In Figures 17 and 18 these subclasses have been grouped together in a way that broadly aligns with the technology fields suggested by WIPO. For readability, some of these technology areas are aggregated if those areas relate to few patents. Conversely, the technology field 'computer technology' encompasses many different applications of AI; this field was therefore restricted and subdivided as shown below.

A patent may be classified in several technology areas; for example, a computer vision system for use in autonomous vehicles could fall within 'image processing', 'recognition of data' and 'transportation'. Classification marks within the G06N subclass were disregarded because the majority of those marks relate to developments in AI technology, rather than their applications per se. Similarly, many of the marks from G06F were excluded because they relate to generic data processing, rather than to specific applications. The 'computer technology' field was therefore subdivided as follows:

G10L, G06F17/2*	Speech recognition, Natural Language Processing
G06T	Image processing
G06K	Recognition of data
G06F17/50	Computer-Aided Design

Appendix 5. Attribution of patents to types of AI technique

The patent abstract serves to summarise the technical content of a patent specification. To estimate relative levels of activity between the various types of AI techniques, the abstract of each patent family was checked for occurrences of the keywords shown below. So, for example, a patent family whose abstract contains the keyword "ant-colony" would be attributed to the "Bio-inspired approaches" category. Patents with multiple keywords may be attributed to multiple categories. The attribution of keywords to types of AI techniques was done using the table below.

Bio-inspired approaches	ant-colony	bee-colony	differential*-evol* algorithm*
	evolution* algorithm*	evolution* comput*	fire-fly
	genetic program*	genetic* algorithm	memetic algorithm*
	particle-swarm*	swarm behav*	swarm intell*
Classification and regression trees	ensemble-learn*	fuzzy-c	kernel learn*
	k-means	multi* label* classif*	random-forest*
	spectral cluster*	vector-machine*	
Neural networks	adversar* network*	auto-encod*	back-propagat*
	back-propogat*	deep-belief network*	deep-learn*
	neural-network	neural-turing	neuro-morph comput*
	transfer-learn*		
Rule learning	association rule	q-learn*	
Supervised learning	collaborat* filter*	ensemble-learn*	factorisation machin*
	factorization machin*	feature engineer*	kernel learn*
	policy-gradient method	q-learn*	random-forest*
	recommender system*	reinforc* learn*	supervised learn*
Unsupervised learning	adversar* network*	auto-encod*	unsupervised learn*

Fuzzy logic	fuzzy environment*	fuzzy logic*	fuzzy number*
	fuzzy set*	fuzzy system*	fuzzy-c
	k-means		

Appendix 6. WO and EP patent applications

International Patent Cooperation Treaty (PCT) patent applications (WO) and European patent applications (EP) may be made through the World Intellectual Property Organization (WIPO) and the European Patent Office (EPO) respectively.

International patent applications may designate any signatory states or regions to the Patent Cooperation Treaty (PCT) and will have the same effect as national or regional patent applications in each designated state or region, leading to a granted patent in each state or region.

European patent applications are regional patent applications which may designate any signatory state to the European Patent Convention (EPC), and lead to granted patents having the same effect as a bundle of national patents for the designated states.

Appendix 7. Relative Specialisation Index

Relative Specialisation Index (RSI) was calculated to account for the fact that some countries file more patent applications than others in all fields of technology. In particular, American, Chinese and Japanese applicants and inventors are prolific patentees. A patent family is associated with a country if any of its inventors or applicants are recorded as being from that country in PATSTAT. The RSI compares the fraction of a country's AI-specific patents, out of all of its patents in all fields of technology, with the corresponding fraction of AI-specific patents worldwide. A logarithm is applied to scale the fractions more suitably – an RSI of zero then represents a country that is no more or less specialised than the worldwide average. The RSI formula is:

$$RSI = \log_{10}\left(\frac{n_i / N_i}{n_{total} / N_{total}}\right)$$

where

n_i = number of AI-specific patents in country i

N_i = total number of AI-specific patents worldwide

n_{total} = total number of patents in country i (from any technology field)

N_{total} = total number of patents worldwide (from any technology field)

Appendix 8. Extending patent coverage

Table 5 shows the percentage of publications in each country (office of first filing) which are subsequently extended and published in more than one country.

Table 5: Percentage of AI patent publications that are published in more than one country (selected countries)	
Publication country	**% publications in more than one country**
China	19%
United States	53%
Korea	55%
Japan	58%
Russian Federation	61%
Taiwan	69%
France	83%
Germany	84%
United Kingdom	88%
WIPO (PCT)	93%
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