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Trends and Priority Shifts in Artificial Intelligence Technology Invention: A global patent analysis

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Trends and Priority Shifts in Artificial Intelligence Technology Invention: A global patent analysis[1]

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Abstract

Artificial intelligence (AI) technology can play a critical role in economic development, resource conservation, and environmental protection by increasing efficiency. This study is the first to apply a decomposition framework to clarify the determinants of AI technology invention. Exploiting data from the World Intellectual Property Organization, this study clarifies the determining factors that contribute to AI technology patent publications based on technology type. Consisting of 13,567 AI technology patents for the 2000-2016 period, our worldwide dataset includes patent publication data from the United States, Japan, China, Europe, and the Patent Cooperation Treaty (PCT). We find that priority has shifted from biological- and knowledge-based models to specific mathematical models and other AI technologies, particularly in the United States and Japan. Our technology type and country comparison shows that the characteristics of AI technology patent publication differ among companies and countries.

Keywords: Artificial intelligence, Patent decomposition analysis, Research and development strategy, Biological model, Knowledge based modeling

JEL classification: O30, O34, L00

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1. Introduction

By enhancing and creating efficiencies, artificial intelligence (AI) technology can play a critical role in improving social well-being in areas as diverse as economic development, precision medicine, public welfare, and environmental protection (National Science and Technology Council, 2016; Parkes and Wellman, 2015). AI technology will significantly contribute to increases in human welfare across a wide range of sectors, including transportation, service robotics, healthcare, education, low-resource communities, public safety, employment, and entertainment (Stone et al., 2016). According to (Teactica, 2015), market opportunities for AI systems will increase from $202.5 million in 2015 to $11.1 billion by 2024.

The global importance of AI technology has been growing. The 2015 Strategy for American Innovation established nine high-priority research areas, including the BRAIN initiative (Insel et al., 2013) and the Precision Medicine initiative (Hodson, 2016). Additionally, AI is listed as a high-priority technology for a super-smart society in Japan's 5th Science and Technology Basic Plan (2016 to 2020). These research and development (R&D) strategies focus on the expansion of the AI business market and are intended to improve international market competitiveness.

Generally, patents grant inventors hold exclusive rights to protect their knowledge and technology from the competitor (Maresh et al., 2016). This action is also observed in A.I.

technology patenting. According to Bajpai (2016), IBM, world largest A.I. patent inventor, has projected that one billion consumers will be reached via Watson by end of 2017, primarily through its partnerships across companies. This report also pointed out sufficient A.I. patenting gives IBM a lead against companies which have just begun to work in the field of A.I. Thus, A.I. patenting is key corporate R&D strategy to have business collaboration with protecting intellectual property and to gain the position in rapid growing market.

Against the backdrop of this acceleration of AI technology development across the globe, the number of patents granted has rapidly increased. Figure 1 shows the number of AI patents granted by application country and technology type and reveals that the number of AI patents has increased more than threefold, i.e., from 708 items in 2012 to 2,888 items in 2016. In particular, AI patents granted in the U.S. increased by 1,628 items during this period (Figure 1(a)), which represents approximately 75% of the AI patent increase worldwide.

<Figure 1 about here>

As shown in Figure 1(b), the patent share of each AI technology type changed from 2012 to 2016. In 2012, biological and knowledge-based models were the leaders in patented AI technologies. However, from 2012 to 2016, the number of patents granted for specific mathematical models and other AI technologies rapidly increased, doubling from 2015 to 2016.

These two figures show the short-term trend of AI patenting based on country and technology. However, Figure 1 is not able to reveal why the number of patents granted for each AI technology type changed.

To clarify why the trend in AI patenting changed, the R&D strategies of the inventors must be clarified. This strategy is the key driver of technology development (Fujii and Managi, 2016). Notably, not all AI technologies contribute equally to improved economic performance. Certain AI technologies directly contribute to profits by creating new products and services, whereas others contribute indirectly and only minimally. Therefore, the incentives for companies to invent AI technologies vary depending on the type of technology considered. A determinant analysis of inventions that focuses on the characteristics of each type of AI technology is important if we are to suggest effective policies to encourage R&D in such technology.

This study is the first to use a decomposition framework to clarify the determinants of AI technology invention. Application of the decomposition method to technological invention was proposed by Fujii and Managi (2016). This application can clarify the main factors that promote innovation, whether they are the corporate priority given to specific technology inventions or the result of the scale effect of R&D activities. This new decomposition application is useful to policymakers because it yields a better understanding of policies at both the macro and micro levels that can effectively encourage the invention of specific AI technology inventions (such as biological, knowledge-based, and specific mathematical models).

The objective of this study is to clarify the determining factors that contribute to AI technology patent publications based on technology type. We also discuss how inventors' industrial characteristics and national R&D policy affect the invention of AI technology by country using company-level data. The novel contribution of this research is to clarify the primary driver of AI patent granting using a patent decomposition framework and the log mean Divisia index analysis. By combining these two approaches, we can distinguish the contribution of the R&D strategy factor and the R&D scale factor. Many previous studies have focused exclusively on the number of patent publications, which is affected by both the priority given to inventions and the scale of research activity (Cecere et al., 2014; Lybbert and Zolas, 2014; Park, 2014; Roper and Hewitt-Dundas, 2015). This study attempts to derive a pure measure of the priority given to inventions from patent publication data by controlling for the scale effect (Fujii, 2016).

To consider the characteristics of each AI technology, we followed the practice of the USPTO and the Japan patent office (JPO) (Appendix 1) and divided the patent data into the following four AI technology groups: (1) biological models, (2) knowledge-based models, (3) specific mathematical models, and (4) other AI technology models.

2. Methodology

We apply a decomposition analysis framework to clarify the changing factors involved in granting AI technology patents. We use the following three indicators to decompose the AI technology patents granted: the priority of a specific AI technology (PRIORITY), the importance of AI technology among all patents granted (AItech), and the scale of R&D activity (SCALE).

We define the PRIORITY indicator as the number of specific AI patents granted divided by the total number of AI patents granted, thus providing the share of specific AI patents granted among total AI patents. This indicator can be increased if the number of specific AI patents granted increases more quickly than the total number of AI patents granted, thus indicating that inventors are concentrating their research resources on specific types of AI technology inventions. Inventors are prioritizing specific AI technology types over other types when PRIORITY is increased.

Similarly, the AItech indicator is defined as the total number of AI patents granted divided by the total number of patents granted, which indicates the share of total AI patents out of total patents. This indicator can be increased if the number of total AI patents granted increases more quickly than the number of total patents granted, thus indicating that inventors are concentrating their research resources on AI technology inventions. Inventors are prioritizing the invention of AI technology over other types of technology when AItech is increased.

The SCALE indicator is defined as the total number of patents granted and thus represents the scale of R&D activities. Generally, active R&D efforts promote the invention of new technologies. Thus, the total number of patents granted reflects the level of active R&D efforts. Additionally, R&D activities in companies depend on corporate financial circumstances because the number patents granted is associated with the cost of researcher salaries, the operating cost of experimental materials, and the cost of applying for and registering patents. For example, following the financial crisis caused by the collapse of Lehman Brothers, the number of patents granted decreased (Fujii and Managi, 2016). Thus, companies with serious financial difficulties decreased their R&D activities to reduce their bankruptcy risk. This decrease in R&D activities led to a decrease in the number of new patents granted, including those related to AI technologies. Therefore, the scale of R&D activity is an important factor in understanding why the number of AI patents granted has changed. SCALE increase as the total number of patents granted increases. The number of patents granted for AI technology would be increased by an increase in overall R&D activities if the SCALE score increased.

Here, we introduce the decomposition approach using the biological model-based technology patent group as a specific type of AI patent granted (Table 1). The number of biological model-based technology patents granted (BIOLOGICAL) is decomposed using the total AI patents granted (AIpatent) and total patents granted (TOTAL), as in equation (1).

<Table 1 about here>

$$\text{BIOLOGICAL}=\frac{\text{BIOLOGICAL}}{\text{AIpatent}}\times\frac{\text{AIpatent}}{\text{TOTAL}}\times\text{TOTAL}=\text{PRIORITY}\times\text{AItech}\times\text{SCALE} \quad (1)$$

We consider the change in biological model-based patents granted from year t-1 (BIOLOGICAL^{t-1}) to year t (BIOLOGICAL^{t}). Using equation (1), the growth ratio of biological model-based patents granted can be represented as follows:

$$\frac{\text{BIOLOGICAL}^{t}}{\text{BIOLOGICAL}^{t-1}}=\frac{\text{PRIORITY}^{t}}{\text{PRIORITY}^{t-1}}\times\frac{\text{AItech}^{t}}{\text{AItech}^{t-1}}\times\frac{\text{SCALE}^{t}}{\text{SCALE}^{t-1}} \quad (2)$$

We transform equation (2) into a natural logarithmic function and thus obtain equation (3). Notably, zero values in the dataset cause problems in the formulation of the decomposition due to the properties of logarithmic functions. To solve this problem, the logarithmic mean Divisia index (LMDI) literature suggests replacing zero values with a small positive number (Ang and Liu, 2007).

$$\ln\text{BIOLOGICAL}^{t}-\ln\text{BIOLOGICAL}^{t-1}=\ln\left(\frac{\text{PRIORITY}^{t}}{\text{PRIORITY}^{t-1}}\right)+\ln\left(\frac{\text{AItech}^{t}}{\text{AItech}^{t-1}}\right)+\ln\left(\frac{\text{SCALE}^{t}}{\text{SCALE}^{t-1}}\right) \quad (3)$$

Multiplying both sides of equation (3) by $\omega_i^t=(\text{BIOLOGICAL}^{t}-\text{BIOLOGICAL}^{t-1})/(\ln\text{BIOLOGICAL}^{t}-\ln\text{BIOLOGICAL}^{t-1})$ yields equation (4) as follows.

$$\begin{aligned}\text{BIOLOGICAL}^{t}-\text{BIOLOGICAL}^{t-1}&=\Delta\text{BIOLOGICAL}^{t,t-1}\\&=\omega_i^t\ln\left(\frac{\text{PRIORITY}^{t}}{\text{PRIORITY}^{t-1}}\right)+\omega_i^t\ln\left(\frac{\text{AItech}^{t}}{\text{AItech}^{t-1}}\right)+\omega_i^t\ln\left(\frac{\text{SCALE}^{t}}{\text{SCALE}^{t-1}}\right)\end{aligned} \quad (4)$$

Therefore, changes in the number of patents granted for biological model-based technologies (⊿BIOLOGICAL) are decomposed by changes in PRIORITY (first term), AItech (second term) and SCALE (third term). The term ω_i^t operates as an additive weight for the estimated number of patents granted for biological model-based technologies. This decomposition technique was developed by Ang et al. (1998). and is termed the LMDI.

The novel aspect of this research is that it clarifies the R&D strategies of companies using LMDI analysis. Many previous studies have focused exclusively on the number of patents granted, which is affected by prioritizing certain invention types and the scale of research activity. This study attempts to derive the pure priority of inventions from patent-granted data by controlling for the scale effect. Fujii (2016) applies a decomposition framework to patent data analysis using the two factors of priority and scale. In this study, we propose an approach developed to distinguish the priority change of specific AI technology and that of total AI technology.

3. Data and results

3.1 Data

We used patent-granted data from PATENTSCOPE, which is provided by the World Intellectual Property Organization (WIPO). The PATENTSCOPE database covers more than 56 million patents granted. We specified AI certain technology patents based on the patent clarification provided by both the USPTO and JPO (Appendix 1). We collected the patent-granted data on 7 February 2017 from the PATENTSCOPE database.

As explained in Table 1, this study focuses on four AI technology types: (1) biological model-based technology (BIOLOGICAL), (2) knowledge-based model technology (KNOWLEDGE), (3) specific mathematical model-based technology (MATHEMATICAL), and (4) other AI technology (OTHER). Following Fujii (2016) and Fujii and Managi (2016) we use only the primary IPC code and the primary applicant name to construct the patent dataset to avoid double-counting patent data.

3.2 Comparative analysis of AI patents granted

3.2.1 When was a specific AI technology patent invented and where?

Table 2 represents the change of AI patents granted by type of technology at each patent office. Table 2 shows that the composition of patent-granted shares differs among countries. The knowledge-based model represents more than half of the total number of AI patents granted by the USPTO, whereas the biological model is the major technology type granted by the SIPO and JPO. Another finding is that the share of the specific mathematical model is only 1.7% in the JPO, which is extremely low compared with that of other patent offices. This outcome occurs because Japanese AI researchers primarily focus on android technology-based R&D (and not mathematical elements), which represents the core AI technology (The Japan News, 2017). PCT, EPO, and the patent offices of other countries exhibit similar trends with respect to the technology share pattern of AI patent publications.

<Table 2 about here>

Next, we consider the numerical change of AI patents granted. As shown in Table 2, all the patent offices except the JPO published the largest number of AI patents from 2015 to 2016. Notably, the number of patents granted more than doubled at the USPTO, SIPO, and PCT. However, the average number of patents granted per year at the JPO was the largest from 2005 to 2009 for the biological model and from 2010 to 2014 for the knowledge-based model.

One interpretation of this result is that the Japanese market is less attractive for AI technology application. Most AI technology services are strongly related to big data collection through the internet (such as social network systems, credit card payments, and sensors). Because of concerns among its residents, Japan is strict regarding the use of private information for business (Kawasaki, 2015). The business barrier regarding big data collection and use minimizes the incentive to obtain AI patents in Japan. In the U.S., the government has established rules and regulations regarding the use of private information as big data (Hardy and Maurushat, 2017; Manyika et al., 2011). Additionally, there are large governmental R&D expenditures for AI technology innovation in the U.S., which is another strong incentive for AI technology development (National Science and Technology Council, 2016).

3.2.2 Who invented which AI technology patent?

Table 3 lists the top 30 applicants for AI patents granted worldwide. The bottom rows represent the number of patents granted to universities in the U.S., China, and Japan. As shown in Table 3, IBM is the world's leading recipient for AI patents granted. Additionally, of the top 30 grantees for AI patents granted, 18 applicants are U.S. companies, 8 applicants are Japanese companies, and 4 applicants are companies from other countries. Notably, Chinese companies and universities are not listed among the top 30 countries evaluated for the 2000-2016 period, which implies that AI patents granted in China are obtained by many applicants.

<Table 3 about here>

Next, we discuss the composition of the AI technology patent share for each applicant. Table 3 indicates that the patent portfolio of AI technology varies among applicants. Qualcomm and BRAIN corporation garnered the highest share for the biological model. However, SAP and Cognitive Scale had the largest share for the knowledge-based model. D-wave obtained 92% of other AI patents, an outcome that represents a completely different trend from other companies. Notably, the companies listed in the top half of the list obtained patents in a wide range of AI technology areas.

According to Table 3, a large proportion of the AI patents granted to Chinese and Japanese universities were for technology based on the biological model. This trend differs from that found for U.S. universities. In addition, U.S. universities have obtained a large proportion of patents for AI technology that uses a knowledge-based model. This trend resembles that found for the composition of patents granted by the USPTO (Table 2). One interpretation of these results is that U.S. universities have an advantage with respect to accessing and analyzing big data. Generally, U.S. universities have more opportunity to collaborate with U.S. companies, which control big data for AI technology development. Access to big data is a key factor in developing a knowledge-based analysis (Gu et al., 2017). Additionally, U.S. universities more successfully train students with substantial analytical talent in graduate school (Manyika et al., 2011) than the universities of other countries. Human resources for big data analysis are another important driver of technology development on the knowledge-based model in the U.S.

3.2.3 Who invented a patented AI technology and where?

In this section, we discuss the distribution of AI patent applications by applicant. As shown in Table 4, most U.S. companies have a large share of AI patent invention according to the USPTO data. By contrast, the share of patented inventions of U.S. companies from the JPO and SIPO is small. With the exception of NTT, non-U.S. companies have more than a 16% patent share at the USPTO. Specifically, Samsung has 61% of all AI patents issued by the USPTO. Surprisingly, four of the eight Japanese companies were granted more AI patents by the USPTO than by the JPO. These results imply that Japanese companies have strong incentives to obtain AI patents from the USPTO, while there is less incentive for U.S. companies to obtain AI patents from the JPO. This result is consistent with the interpretation that big data use creates an advantage for the U.S. market with respect to AI technology application.

<Table 4 about here>

Based on Table 4, universities clearly tend to apply for AI patents at domestic patent offices. In particular, 98% of the AI patents obtained by Chinese universities were granted by the SIPO, with a low number granted by other patent offices. By contrast, U.S. and Japanese universities apply for AI patents at the PCT in addition to at their domestic patent offices. Notably, approximately 45% of the AI technology patents granted in China were obtained by Chinese universities. This outcome is unique. In other countries, private companies are the primary patent applicants. This trend is also observed in other technological fields (e.g., nanotechnology (Huang and Wu, 2012) and aquaculture technology) (Fujii et al., 2017). Fong et al. (2015) note that "China's National Medium and Long Term Science and Technology Development Planning (2006–2020)" significantly improved Chinese university technology transfer. Additionally, the same scholars conclude that economic incentives and royalties are key factors incentivizing the increase in the number of patented inventions at Chinese universities.

Moreover, the Chinese government sets a high priority on AI technology development in China's 13th Five-Year Plan (2016-2020). Under this plan, research institutes and universities are encouraged to invent new AI technologies. These governmental targets can be considered the key factor driving the increase in the priority placed on AI technology in China.

3.3 Patent decomposition analysis

Figure 2 shows the results of a decomposition analysis for four specific AI technology patents granted at all the patent offices listed in Appendix 2. Because the AI patent trend changes beginning in 2012 (Figure 1), we divided the decomposition analysis results into two periods (the first period runs from 2000 to 2011, and the second period from 2012 to 2016). The plotted point in red indicates the change in the number of specific patents granted, and the bar chart shows the effects of each decomposed factor on the number of patents granted related to specific AI technologies. The sum of the bars is equivalent to the value of the plotted point. The figure shows the differences in the driving factors for patents granted based on the type of AI technology. Detailed results from the decomposition analysis are provided in Appendices 3-6.

<Figure 2 about here>

Figure 2 shows that the number of patents granted for technology based on the biological and knowledge-based models increased during the first period. However, the priority of specific AI technology affects these two technology types differently. As shown in Figure 2, during the first period, the relative priority of the biological model was negative, whereas that of the knowledge-based model was positive. This result implies that the priority of AI technology patent invention shifted from the biological model to the knowledge-based model over the first period. The number of patents granted for the other two technology types did not change significantly during the first period, which indicates that these two technologies were treated as less important than technologies based on the biological and knowledge-based models during that period.

Based on the results for the second period, the number of patents granted substantially increased for all four AI technologies. In addition, the priority of specific technologies shifted from the biological and knowledge-based models to the specific mathematical model and other AI model during the second period. Specifically, the number of patents granted for other AI technology was 624 items during the second period, which is more than that for the biological model (565 items) and close to that for the knowledge-based model (693 items) (see red points in Figure 2).

There are two main reasons why the number of patents granted for other AI technology increased during the second period. First, technology based on the biological and knowledge-based models that use big data have garnered attention in the business market in recent years as the technology demand for high information-processing capabilities became stronger. This technology demand exerted a strong incentive to invent the quantum computer, which is categorized as other AI technology (Lloyd et al., 2016).

Second, the range of AI technology became broader and more complex during the second period, which makes it difficult to categorize AI technology patents into the major technology groups, such as the biological model or the knowledge-based model. Here, we examine the breakdown for AI technology patents whose primary IPC code is G06N99 to investigate the primary driver of other AI technology patent growth. There are 611 items whose IPC is solely G06N99 that are not registered using a secondary IPC code. The number of patents whose second IPC is G06N5/02, G06N5/04, or G06N7/00 total 83, 129, and 106 items, respectively. These IPC codes are included under the knowledge-based model and specific mathematical models (Appendix 1). Thus, other AI technology patents includes patent items that are strongly related to knowledge-based or specific mathematical models.

Patent items categorized as other AI technology and registered with a second IPC code of G06F17/30 (information retrieval; therefore, database structures) include 86 items from 2000 to 2015 and 77 items published after 2015. This technology group contributes to creating data labeling and tagging to achieve more efficient machine learning. For example, IBM listed

“Labeling of data for machine learning (US20150356457)”, and Microsoft listed “Metadata tag description generation” in publication number US20160358096. These AI patents involve crucial technology that is used to rapidly analyze big data collected by social network services and sensors for the Internet of Things. However, there is no appropriate IPC clarification for these technologies, and such patent items are registered under other AI technology.

Table 5 shows the patent decomposition analysis results by patent office. The table shows that the main contributors of patents granted are mixed in the first period among the patent offices. However, AI technology commonly contributed as the main driver of patent invention for the biological and knowledge-based models during the second period at all the patent offices. Additionally, the priority of a specific technology increased other AI technology at all the patent offices during the second period. Based on these two findings, the R&D priority of AI technology became stronger during the second period—particularly for other AI technology—at the five patent offices. In addition, the priority of specific mathematical models increased at the USPTO and JPO but decreased at the EPO. Thus, the priority of specific technology commonly contributed to other AI technology invention at the five patent offices and the specific mathematical model at the USPTO and JPO.

<Table 5 about here>

The key point of the results for the first period is that the scale change of R&D activity contributes at the SIPO for all four AI technology types. One interpretation of this trend is that the Chinese patent application law revisions in 2001 and 2009 simplified patent applications for domestic companies that used the subsidy program (Dang and Motohashi, 2015). Hu et al. (2017) noted that a rapid patent application increase at the SIPO was caused by external factors, such as the revision of the patent law and a new subsidy system and not by internal factors (e.g., R&D priority changes and human resources for R&D). Thus, the revision of the Chinese patent application system contributed to expanding R&D activities (e.g., patent applications) at the SIPO, which increased the number of patents for AI inventions.

At the USPTO, the priority of AI technology increased the number of patents granted for the four AI technology types during both the first and second periods. This result was observed only at the USPTO and indicates that AI patent invention behavior in the U.S. is unique and successfully incentivized by U.S. governmental policies (National Science and Technology Council, 2016; Taylor, 2016). Additionally, the contribution of the priority of specific technology shifted from the knowledge-based model to the specific mathematical model and other AI technology at the USPTO and JPO during the second period. Nonetheless, the priority of specific technology negatively affected the specific mathematical models at the SIPO, PCT, and EPO.

4. Summary and conclusions

This study examined the trend and priority change of AI technology using patent-granted data from 2000 to 2016. We focused on the following four technology types: (1) biological model, (2) knowledge-based model, (3) specific mathematical model, and (4) other AI technology. Employing a patent decomposition analysis framework, we clarified the trends and priority changes for patent inventions for these four technology types. The main results are summarized as follows.

First, AI technology patents were primarily granted at the USPTO to private U.S. companies, and in particular to IBM, Microsoft, and Qualcomm. Additionally, many U.S. companies primarily applied for patents at the USPTO and have little share at other patent offices. Non-U.S. companies also focused on obtaining patents from the USPTO in addition to their domestic patent offices. These results show that the U.S. market is attractive for both U.S. and non-U.S. companies. However, other countries' markets are not particularly attractive for U.S. companies.

Second, universities are key AI technology inventors in the U.S. and China. Specifically, 45% of AI technology patents granted at the SIPO were obtained by Chinese universities. Other important findings include that 98% of the AI technology patents granted to Chinese universities were registered at SIPO, whereas U.S. and Japanese universities received 72% and

78% of their relevant patents from domestic patent offices, respectively.

Finally, we find that the relative priority of R&D shifted from the biological and knowledge-based models to specific mathematical models and other AI technology, particularly in the U.S. and Japan. Additionally, R&D priority characteristics vary among the patent offices and AI technology types. These results imply that the international framework for AI technology development should be considered for effective R&D policy construction.

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Table 1. Description of AI technology patent group

Patent group	Description of patent group [IPC code]
Biological model	Computer systems based on biological models, including neural network models, genetic models, architectures, physical realization, learning methods, biomolecular computers, and artificial life [IPC=G06N3/00].
Knowledge-based model	Computer systems that utilize knowledge-based models, including knowledge engineering, knowledge acquisition, extracting rules from data, and inference methods or devices [IPC=G06N5/00].
Specific mathematical model	Computer systems based on specific mathematical models, including fuzzy logic, physical realization, chaos models or non-linear system models, and probabilistic networks [G06/N7/00].
Other AI technology	Subject matter not provided for previously described groups of the G06N3 subclass, including quantum computers, learning machines, and molecular computers [G06/N99/00].

Source: USPTO Class 706 Data processing: Artificial intelligence.

Report on FY2014 Trend survey of patent application technology: Artificial intelligence

(2016) https://www.jpo.go.jp/shiryou/pdf/gidou-houkoku/26_21.pdf.

Table 2. Data description of AI technology patents granted (item)

Patent office	AI technology type	2000-2016	Share	Yearly average number of patents granted			
				2000-2004	2005-2009	2010-2014	2015-2016
USPTO	Biological	1,455	19.9%	44	63	80	259
	Knowledge	4,152	56.9%	50	166	320	738
	Mathematical	672	9.2%	9	18	30	194
	Other	1,019	14.0%	1	3	57	359
SIPO	Biological	1,184	73.7%	9	32	103	232
	Knowledge	219	13.6%	1	9	16	45
	Mathematical	114	7.1%	4	6	8	14
	Other	90	5.6%	1	7	4	15
JPO	Biological	679	56.4%	12	62	46	40
	Knowledge	410	34.1%	4	31	37	25
	Mathematical	21	1.7%	1	1	1	5
	Other	94	7.8%	1	4	3	26
PCT	Biological	723	46.3%	35	30	38	104
	Knowledge	480	30.7%	18	26	29	58
	Mathematical	114	7.3%	2	5	9	16
	Other	244	15.6%	7	8	12	56
EPO	Biological	452	44.0%	26	24	24	42
	Knowledge	306	29.8%	8	22	20	26
	Mathematical	106	10.3%	2	5	10	12
	Other	164	16.0%	7	8	10	22
Other patent office	Biological	434	49.9%	25	13	31	45
	Knowledge	220	25.3%	10	8	17	23
	Mathematical	135	15.5%	4	3	13	16
	Other	80	9.2%	3	4	5	9

Source: Author estimate using IPC code in Appendix 1 and PATSTAT database.

Note: USPTO: United States Patent and Trademark Office; SIPO: State Intellectual Property Office of The People's Republic of China; JPO: Japan Patent Office; PCT: Patent Cooperation Treaty; EPO is European Patent Office.

Table 3. Number of AI patents granted and technology portfolios: 2000 to 2016

Rank	Applicant name	Country	Total patents	Patent portfolio of AI technology			
				Biological	Knowledge	Mathematical	Other
1	IBM	USA	1,057	22%	56%	8%	14%
2	Microsoft	USA	466	22%	44%	9%	24%
3	Qualcomm	USA	450	83%	7%	3%	7%
4	NEC	Japan	255	23%	49%	8%	20%
5	Sony	Japan	212	51%	33%	6%	10%
6	Google	USA	195	41%	36%	7%	17%
7	Siemens	Germany	192	54%	31%	10%	5%
8	Fujitsu	Japan	154	27%	60%	9%	4%
9	Samsung	Korea	119	56%	28%	3%	13%
10	NTT	Japan	94	35%	49%	0%	16%
11	Hewlett-Packard	USA	93	22%	44%	4%	30%
12	Yahoo	USA	88	14%	57%	16%	14%
13	Toshiba	Japan	86	22%	57%	7%	14%
14	D-wave	Canada	77	1%	4%	3%	92%
15	Hitachi	Japan	69	20%	38%	12%	30%
15	SAP	USA	69	23%	70%	6%	1%
17	Canon	Japan	68	59%	28%	3%	10%
18	Xerox	USA	62	15%	45%	18%	23%
19	GE	USA	59	14%	59%	22%	5%
20	Mitsubishi Electric	Japan	53	49%	43%	2%	6%
21	Honeywell	USA	49	24%	51%	22%	2%
22	Boeing	USA	48	31%	60%	4%	4%
23	Cisco	USA	47	15%	38%	0%	47%
23	Oracle	USA	47	17%	55%	9%	19%
25	British Telecomm	UK	44	41%	57%	2%	0%
26	Intel	USA	43	35%	51%	5%	9%
27	Amazon	USA	41	15%	39%	2%	44%
28	Brain Corporation	USA	40	80%	15%	3%	3%
28	Cognitive scale	USA	40	0%	88%	0%	13%
28	Facebook	USA	40	0%	40%	13%	48%
	University total	World	1,177	69%	19%	6%	6%
	U.S. university	USA	241	41%	38%	7%	14%
	Chinese university	China	725	82%	10%	5%	3%
	Japanese university	Japan	93	83%	15%	1%	1%

Source: Author estimate using IPC code in Appendix 1 and PATSTAT database.

Table 4. Distribution of country or organization of AI patents granted from 2000 to 2016

Rank	Applicant name	Country	USPTO	SIPO	JPO	PCT	EPO	Other
1	IBM	USA	90%	0%	4%	4%	1%	1%
2	Microsoft	USA	74%	1%	4%	14%	7%	1%
3	Qualcomm	USA	32%	8%	8%	30%	10%	13%
4	NEC	Japan	36%	0%	33%	25%	5%	1%
5	Sony	Japan	32%	9%	36%	11%	10%	1%
6	Google	USA	75%	0%	0%	14%	8%	3%
7	Siemens	Germany	28%	3%	4%	29%	24%	13%
8	Fujitsu	Japan	42%	1%	31%	15%	10%	1%
9	Samsung	Korea	61%	6%	3%	0%	16%	14%
10	NTT	Japan	0%	0%	99%	0%	1%	0%
11	Hewlett-Packard	USA	71%	0%	3%	20%	4%	1%
12	Yahoo	USA	86%	0%	13%	1%	0%	0%
13	Toshiba	Japan	45%	2%	35%	14%	3%	0%
14	D-wave	Canada	39%	5%	0%	35%	0%	21%
15	Hitachi	Japan	30%	0%	28%	29%	13%	0%
16	SAP	USA	74%	0%	4%	1%	20%	0%
17	Canon	Japan	47%	1%	37%	10%	4%	0%
18	Xerox	USA	89%	0%	2%	0%	8%	2%
19	GE	USA	85%	0%	2%	7%	0%	7%
20	Mitsubishi Electric	Japan	25%	0%	57%	8%	11%	0%
21	Honeywell	USA	39%	10%	2%	10%	33%	6%
22	Boeing	USA	60%	2%	4%	15%	19%	0%
23	Cisco	USA	85%	0%	0%	9%	6%	0%
24	Oracle	USA	100%	0%	0%	0%	0%	0%
25	British Telecomm	UK	16%	0%	0%	25%	41%	18%
26	Intel	USA	67%	0%	2%	19%	9%	2%
27	Amazon	USA	80%	0%	0%	12%	7%	0%
28	Brain Corporation	USA	80%	0%	0%	20%	0%	0%
28	Cognitive scale	USA	100%	0%	0%	0%	0%	0%
28	Facebook	USA	100%	0%	0%	0%	0%	0%
	University total	World	20%	61%	7%	9%	0%	3%
	U.S. university	USA	72%	1%	0%	21%	0%	6%
	Chinese university	China	1%	98%	0%	1%	0%	0%
	Japanese university	Japan	3%	2%	78%	16%	0%	0%

Source: Author's estimation using the IPC code in Appendix 1 and PATSTAT database.

Note: USPTO: United States Patent and Trademark Office; SIPO: State Intellectual Property Office of The People's Republic of China; JPO: Japan Patent Office; PCT: Patent Cooperation Treaty; EPO: European Patent Office.

Table 5. Results of decomposition analysis by patent office: 2000 to 2016

Specific technology	Patent office	Change from 2000 to 2012				Change from 2012 to 2016			
		⊿Specific technology patent	Decomposed factors			⊿Specific technology patent	Decomposed factors		
			Priority (specific)	Priority (AI)	Scale		Priority (specific)	Priority (AI)	Scale
Biological model	USPTO	39	-73.2	85.2	26.9	260	-10.6	286.0	-15.3
	SIPO	89	22.9	-9.1	75.1	183	-14.3	109.6	87.7
	JPO	39	-17.9	73.5	-16.6	-4	-12.1	28.3	-20.3
	PCT	-3	-16.4	-8.5	21.9	74	-10.9	75.8	9.2
	EPO	19	-17.3	26.0	10.4	29	5.1	29.6	-5.7
Knowledge-based model	USPTO	239	85.2	123.8	30.0	612	-292.6	938.3	-33.8
	SIPO	13	0.0	2.6	10.3	36	1.7	19.0	15.3
	JPO	40	38.2	12.3	-10.4	-19	-25.1	18.2	-12.1
	PCT	11	5.7	-10.0	15.3	48	-7.6	48.9	6.7
	EPO	11	7.4	-1.6	5.2	12	-4.5	18.8	-2.3
Specific mathematical model	USPTO	15	-6.9	14.3	7.5	265	122.6	156.8	-14.4
	SIPO	4	-10.6	3.6	11.0	10	-0.5	5.8	4.7
	JPO	0	-0.1	0.3	-0.2	8	7.6	1.4	-1.0
	PCT	2	2.0	-1.3	1.2	15	-1.0	14.3	1.7
	EPO	12	12.2	-1.4	1.3	-1	-8.6	9.3	-1.7
Other AI technology	USPTO	10	4.6	4.4	1.0	491	191.5	326.9	-27.4
	SIPO	3	-5.5	-0.7	9.2	21	14.7	3.5	2.8
	JPO	2	-3.1	6.4	-1.3	34	30.7	11.4	-8.2
	PCT	9	5.7	-1.9	5.2	54	21.1	29.6	3.3
	EPO	8	4.7	0.3	3.0	21	9.3	14.5	-2.8

Note: USPTO: United States Patent and Trademark Office; SIPO: State Intellectual Property Office of The People's Republic of China; JPO: Japan Patent Office; PCT: Patent Cooperation Treaty; EPO: European Patent Office.

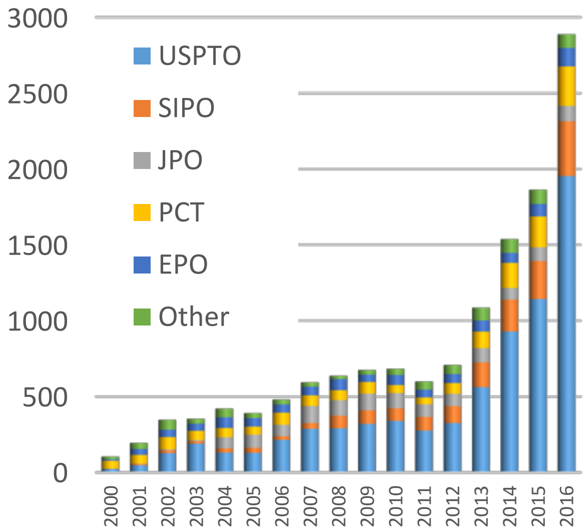


Figure 1a. Number of AI patents granted by country

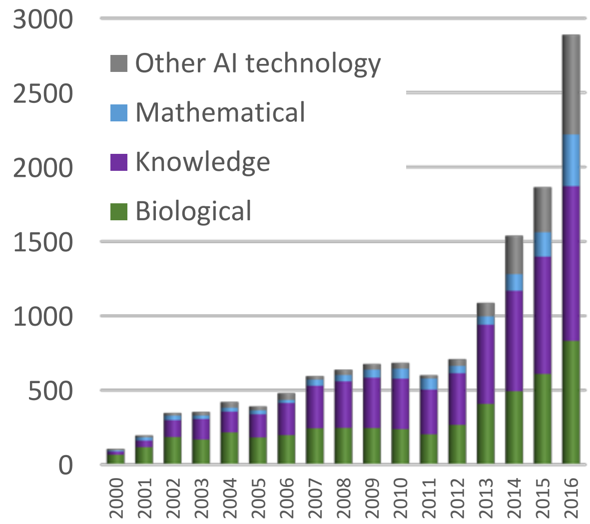


Figure 1b. Number of AI patents granted by technology

Figure. 1. Trend of AI patents granted: 2000 to 2016 (number of items)

Source: Author estimate using IPC code in Appendix 1 and PATSTAT database.

Note: USPTO: United States Patent and Trademark Office; SIPO: State Intellectual Property Office of The People's Republic of China; JPO: Japan Patent Office; PCT: Patent Cooperation Treaty; EPO: European Patent Office

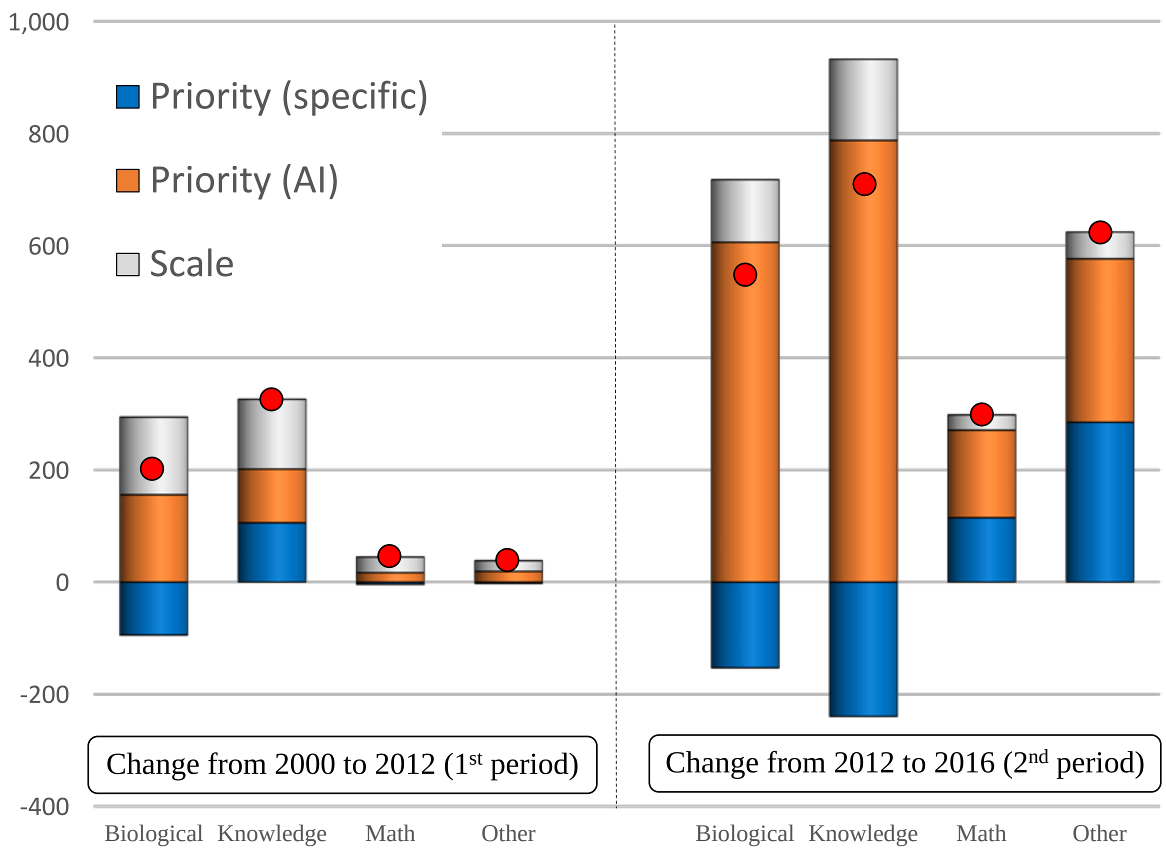


Figure. 2. Results of patent decomposition analysis (number of items)

Note: The vertical axis is standardized by setting the number of changes in patents granted in 2000 and 2012 to zero.

Supplementary Information

Appendix 1. International patent clarification related to AI technologies

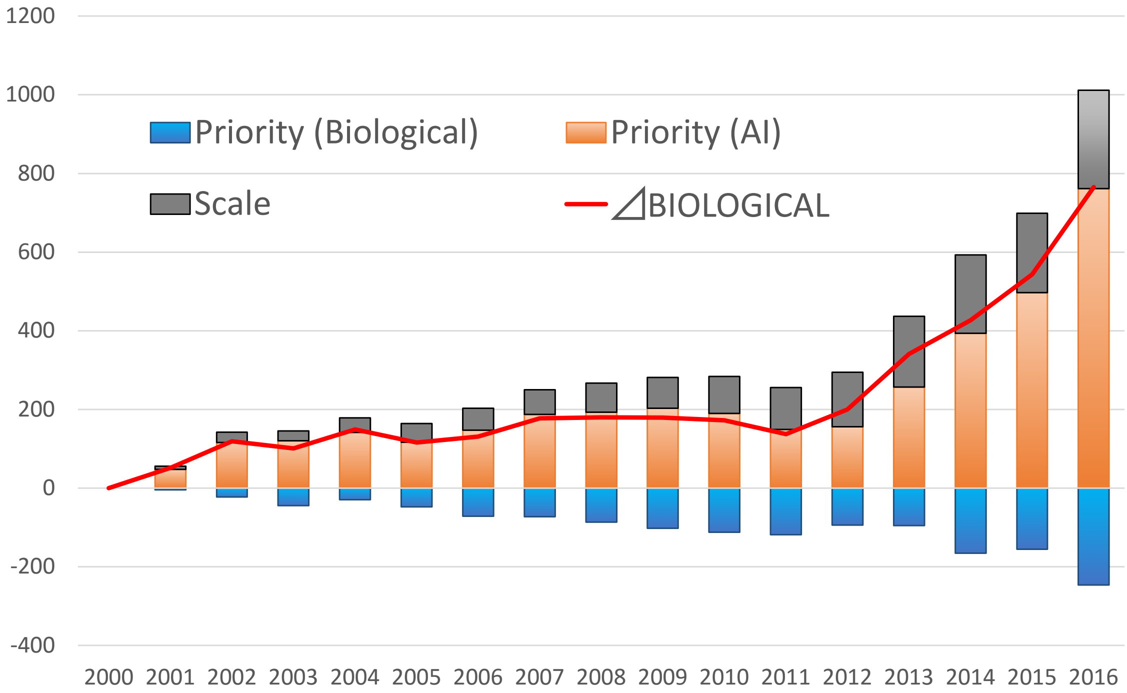
IPC	Technology group	Description
G06N 3/00	Biological model	Computer systems based on biological models
G06N 3/02	Biological model	Using neural network models
G06N 3/04	Biological model	Architectures
G06N 3/06	Biological model	Physical realization
G06N 3/063	Biological model	Using electronic means
G06N 3/067	Biological model	Using optical means
G06N 3/08	Biological model	Learning methods
G06N 3/10	Biological model	Simulation on general-purpose computers
G06N 3/12	Biological model	Using genetic models
G06N 5/00	Knowledge-based model	Computer systems utilizing knowledge-based models
G06N 5/02	Knowledge-based model	Knowledge representation
G06N 5/04	Knowledge-based model	Inference methods or devices
G06N 7/00	Specific mathematical model	Computer systems based on specific mathematical models
G06N 7/02	Specific mathematical model	Using fuzzy logic
G06N 7/04	Specific mathematical model	Physical realization
G06N 7/06	Specific mathematical model	Simulation on general-purpose computers
G06N 7/08	Specific mathematical model	Using chaos models or non-linear system models
G06N 99/00	Other AI technology	Subject matter not provided for in other groups of this subclass

Source: USPTO Class 706 Data processing: Artificial intelligence.
Report on FY2014 Trend survey of patent application technology: Artificial intelligence (2016) https://www.jpo.go.jp/shiryou/pdf/gidou-houkoku/26_21.pdf.

Appendix 2. Patent data collection period in Patentscope database by country

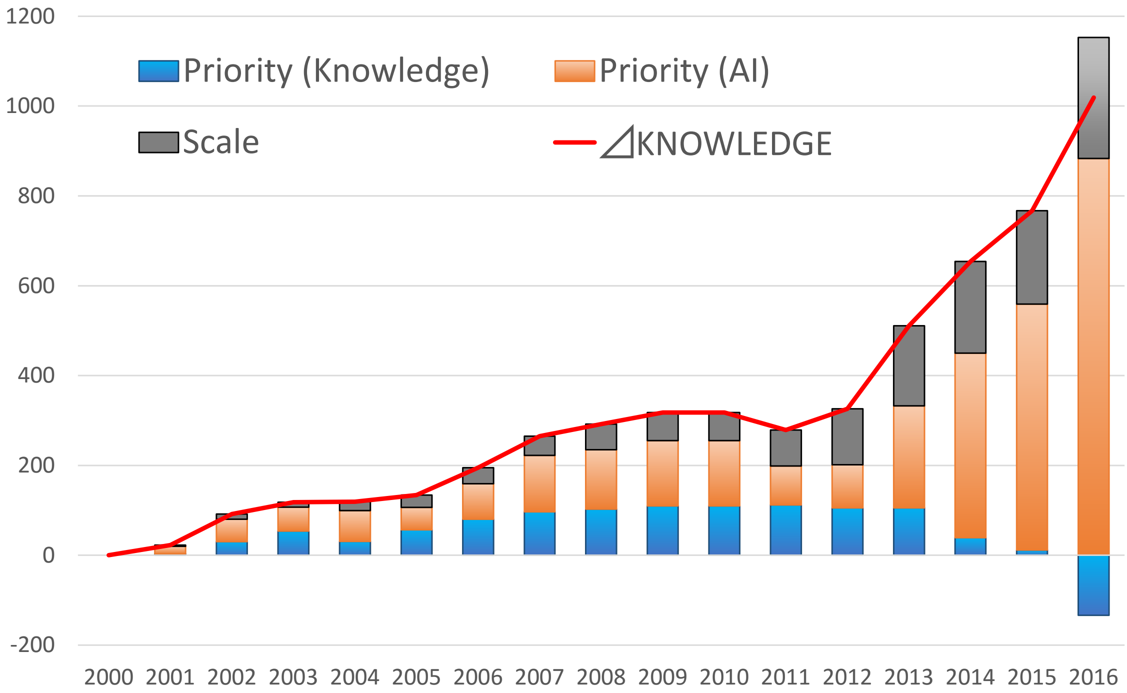
Country	Data collection period		Country	Data collection period
PCT	20.10.1978–16.12.2016		Jordan	31.12.1899–16.03.2016
Argentina	12.02.1965–24.03.2016		Kenya	12.05.1996–01.02.2011
Bahrain	10.03.1957–29.09.2005		Mexico	02.12.1991–03.06.2016
Brazil	26.04.1972–07.09.2016		Morocco	07.07.1977–01.06.2016
Canada	12.08.1869–27.11.2016		Nicaragua	23.12.1982–07.02.2014
Chile	20.04.2000–28.05.2016		Panama	10.03.1990–30.10.2013
China	05.01.1989–10.11.2016		Peru	22.02.1989–01.01.2016
Colombia	14.02.1995–01.07.2016		Portugal	24.06.1967–01.07.2016
Costa Rica	03.10.0108–30.07.2016		Republic of Korea	27.07.1979–01.09.2016
Cuba	13.03.1968–01.09.2016		Russian Federation	16.02.1993–28.11.2016
Dominican Rep.	11.05.1964–01.07.2016		Russian Federation (USSR data)	01.03.1919–28.11.2016
Ecuador	02.10.1990–01.05.2015		Singapore	29.11.1995–31.08.2016
Egypt	02.01.2002–31.10.2014		South Africa	27.01.1983–30.07.2015
El Salvador	11.03.1970–25.06.2016		Spain	15.03.1827–17.08.2016
Estonia	18.10.1994–16.11.2016		Tunisia	01.01.1999–31.03.2016
Eurasian Patent Office	02.07.1996–01.09.2016		United Arab Emirates	02.07.2002–03.01.2013
Germany	03.07.1877–25.11.2016		United Kingdom	05.07.1782–13.10.2016
Germany (DDR data)	15.06.1951–23.04.1999		United States of America	01.08.1790–14.12.2016
Guatemala	31.12.1961–18.06.2016		Uruguay	17.08.1990–30.07.2016
Honduras	30.01.2004–28.04.2015		Viet Nam	26.05.1997–27.04.2010
Israel	02.01.1900–01.11.2016		ARIPO	04.07.1985–29.07.2008
Japan	09.01.1993–11.11.2016		European Patent Office	21.12.1978–24.11.2016

Source: World Intellectual Property Organization, National Collections–Data Coverage. https://patentscope.wipo.int/search/en/help/data_coverage.jsf



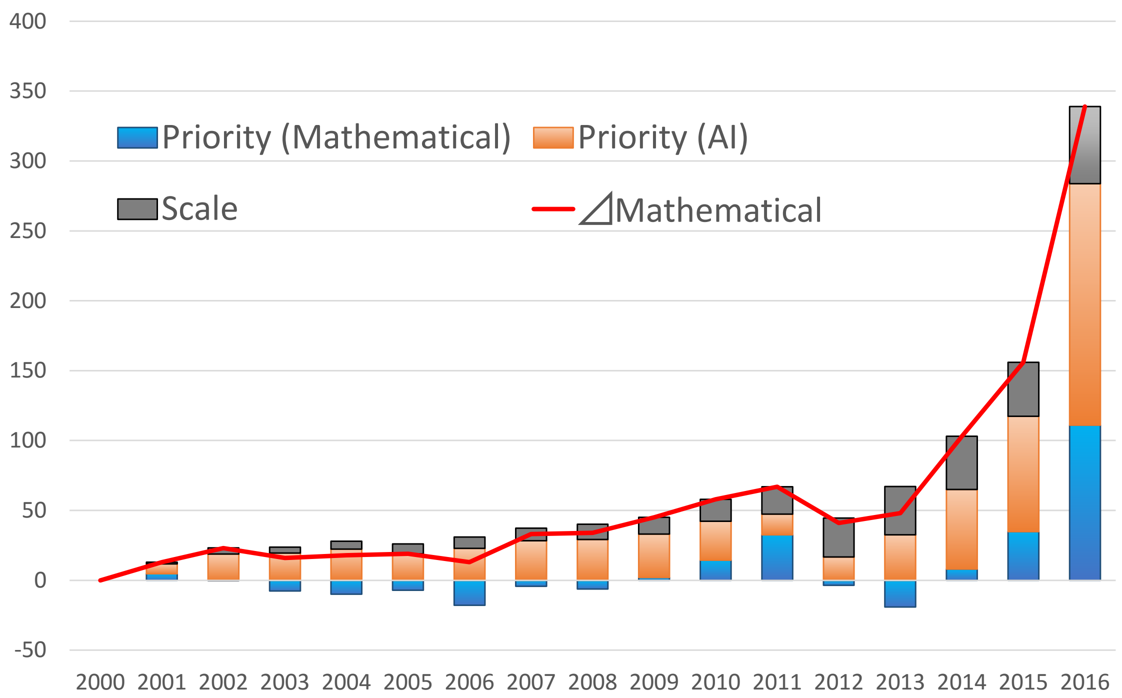
Appendix 3. Decomposition analysis of patents granted for the biological model (number of items)

Note: The vertical axis is standardized by setting the number of changes in patents granted in 2000 to zero.



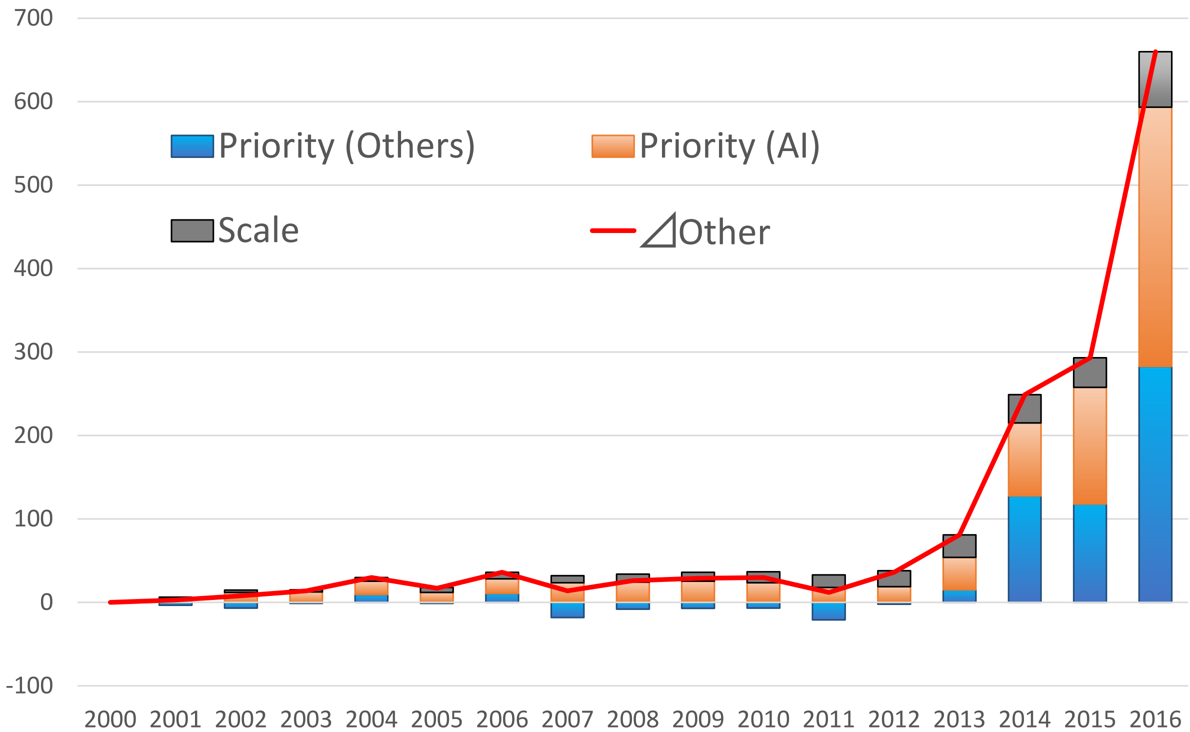
Appendix 4. Decomposition analysis of patents granted for the knowledge-based model (number of items)

Note: The vertical axis is standardized by setting the number of changes in patents granted in 2000 to zero.



Appendix 5. Decomposition analysis of patents granted for specific mathematical model (number of items)

Note: The vertical axis is standardized by setting the number of changes in patents granted in 2000 to zero.



Appendix 6. Decomposition analysis of patents granted for other AI technology (number of items)

Note: The vertical axis is standardized by setting the number of changes in patents granted in 2000 to zero.