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The Review of Chinese Artificial Intelligence Labor Market: Both in Figures and Skills

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Abstract. Artificial intelligence (AI) is entering a new phase of its development. Among the main competing countries for leadership in this area are the US and China. The US is the biggest player in the development and implementation of artificial intelligence in terms of algorithms and equipment, while China is actively building its capacity due to the availability of data for training, which creates a strategic advantage for China over the United States. In 2021 Chinese researchers ranked number one in the world in terms of citations in peer-reviewed Q1 scientific journals. The analysis of vacancies in the field of artificial intelligence, posted on the websites of Chinese recruitment agencies for more than 200 names of professions, as well as the list of competences of specialists in these professions allowed to determine the in-demand occupations and skills in the field of artificial intelligence in China. The lists of competencies for the most in-demand AI occupations in China will serve as a basis for transferring the competency model of the Chinese artificial intelligence specialist to the Russian high-tech labour market. In conclusion, it should be noted that China starting with similar conditions with some other countries, having competent strategic planning for a long term period as well as huge finances, 5 years after adoption of the fundamental "Next Generation Artificial Intelligence Development Plan" in 2017 is breaking into a leading position in the world.

Keywords: artificial intelligence, China, AI specialists, AI companies, training, AI occupations, Industry 5.0.

Research area: social structure, social institutions and processes (socio-logical sciences); regional and sectoral economy.

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Обзор китайского рынка труда в сфере ИИ: числом и уменьем

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Аннотация. Сфера искусственного интеллекта (ИИ) выходит на новый виток своего развития. Среди главных конкурирующих стран за лидерство в данной сфере выступают США и Китай. США являются крупнейшим игроком в сфере развития и внедрения искусственного интеллекта в части алгоритмов и оборудования, в то же время Китай активно наращивает свой потенциал благодаря доступности данных для обучения, что создаёт стратегическое преимущество Китая над США. В 2021 году китайские исследователи вышли на первое место в мире по количеству цитируемых публикаций в рецензируемых научных журналах Q1 (топ-25 % журналов). Анализ научных статей, патентов, диссертаций по тематике ИИ в китайской базе данных China National Knowledge Infrastructure (CNKI) за последние 10 лет (2011–2021 гг.) продемонстрировал топовые тематики китайских университетов в области ИИ. В 2022 году университеты Китая отходят на второе место, и резкий рост ИИ-публикаций фиксируется у китайских технологических гигантов, Университет Цинхуа с 1-го места уходит на 4-е. При этом большинство работ китайских технологических гигантов в 2022 году в сфере ИИ – это патенты. Анализ размещённых на веб-сайтах китайских рекрутинговых агентств вакансий в сфере ИИ по более 200 наименований профессий, а также перечня компетенций специалистов по этим профессиям позволил определить востребованные профессии и компетенции в сфере искусственного интеллекта в Китае. Сформированные перечни компетенций в области наиболее востребованных профессий в сфере искусственного интеллекта в Китае послужат основой для трансфера компетентностной модели китайского ИИ-специалиста на российский высокотехнологичный рынок труда. В заключении отмечаем, что при схожих стартовых условиях с другими странами Китай, обладая грамотным стратегическим планированием на долгосрочную перспективу и большими финансовыми вливаниями, уже спустя 5 лет после принятия фундаментального “Плана развития искусственного интеллекта нового поколения” в 2017 году вырывается на лидирующие позиции в мире.

Ключевые слова: искусственный интеллект, Китай, ИИ-специалисты, ИИ-компании, подготовка кадров, ИИ-профессии, Industry 5.0.

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Introduction

At present, artificial intelligence (AI) technologies have come close to implementation in various areas of modern society. AI refers to technologies in the field of computer vision, speech recognition and synthesis, biometric recognition, intelligent data analysis, etc., which implement human cognitive functions. Thanks to a wide range of application of AI technologies, the development of industry, transport, communication, financial sphere, labour efficiency is increased, human resource structures are optimised, and new high-tech jobs are created (Guerrero et al., 2019). Digitalisation is a major driver of 21st century manufacturing, with changes in products, production processes and business models. In the broad category of digitalisation, Industry 4.0 has become a well-established concept among politicians, business leaders and academics (Barzotto et al., 2020; Hanna, 2018; Lund, Vildasen, 2022). In this regard, artificial intelligence attracts the attention of both academics and practitioners in various fields of economics.

For the world's leading powers (China, USA, UK, Germany, Japan), it is becoming extremely important to support AI development capabilities in order to maintain global leadership in various fields. Thus, among the companies that received the largest number of patents in the field of AI in 2021 were high-tech companies IBM (1,813 applications, USA), Google (1,167 applications, USA), Intel (1,131 applications, USA), Microsoft (948 applications, USA), Baidu (317 applications, China), Tencent (306 applications, China), Huawei (272 applications, China), Bosch (590 applications, Germany) and Siemens (333 applications, Germany) (Artificial life and the meta-universe, 2022).

The US is the largest player in the development and deployment of artificial intelligence in terms of algorithms and hardware, while at the same time China is actively building its capacity due to the large amount and availability of data for training, which creates a strategic advantage for China over the US. For example, the average age of companies at the time they reach unicorn status (a startup that has reached a billion dollars within 10 years of founding) is only 5 years in China, 10 years in the EU, and 8 years in the US (Jinzhi, Carrick, 2019).

The aim of the study is to form lists of the most demanded AI professions in China and the competencies declared by employers for these professions in order to transfer the competence model of the Chinese AI specialist to the Russian high-tech labour market based on the analysis of scientific publications, posted vacancies on recruitment agencies' portals.

In order to achieve the aim of the article, the following tasks are addressed:

1) analysing scientific publications and strategic documents on China's AI sphere;

2) highlighting the priority AI technologies and key economic sectors in the AI sphere in China;

3) analysing the human resource potential in the AI field in China;

4) comparative analysis of the salary range of AI professionals in China and Russia.

5) identification of priority professions and competences based on the analysis of vacancies in the Chinese AI sphere.

Literature Review

Chinese researchers in 2022 are writing about the formation of "Industry 5.0," which follows the four early stages: hunter-gatherer, agricultural, industrial, and information societies (Lv et al., 2022). The concept of Industry 5.0 is to utilise the unique creativity of human experts in collaboration with powerful, intelligent

and precise machines. Many technology visionaries believe that "Industry 5.0" will bring back human interest in manufacturing. "Industry 5.0" will greatly improve the efficiency of production by creating versatility between humans and machines, providing collaboration and responsibility for continuous monitoring of activities. Co-operation between people and machines is aimed at rapidly advancing production. "Industry 5.0" can improve the quality of production by assigning repetitive and monotonous tasks to robots/machines as well as tasks that require human critical thinking. Above all, in Industry 5.0, the application of artificial intelligence technology can save labour and comprehensively improve production efficiency and product quality.

A number of foreign authors, including Chinese authors, have noted a surge in patent activity in artificial intelligence and robotics in recent years, suggesting that solutions based on AI technologies could begin to impact the economy (Damioli et al., 2021; Lee, Trimi, 2018; Li at el., 2023; Niggli, Rutzer 2023; Olokundun et al., 2022; Vannutelli et al., 2022).

A. Zogner in his review on "Technological progress, transformation of labour markets and demand for competences" considers the changing needs for professional competences and approaches to the formation of in-demand skills at the level of individual workers, companies and regions with the use of artificial intelligence technologies (Sorgner, 2019).

Chinese authors pay special attention to serious environmental issues and the rapid development of digital technology, and enterprises' green innovation and digitalisation strategies have attracted much attention. There are still few studies linking green innovation with enterprise digitalisation and exploring the internal mechanism of this relationship (Ning, 2023).

Also of interest are works of Yu Jia He (He, 2017) and Dominic Barton (Barton et al., 2017), which analyses the status and potential of artificial intelligence in China. The paper "Artificial intelligence: implications for China" lists various government support measures for artificial intelligence and strategic priorities in AI development for China:

– building a robust data ecosystem;
– widespread adoption of AI in traditional industries;
– strengthening AI human resources capacity;
– ensuring that the education system is ready to develop technological skills and retrain large segments of the workforce;
– establishing ethical and legal consensus.

The implications of the introduction of artificial intelligence for the country are emphasised:

– social (potential to improve human well-being by improving health, environment, security and education; emergence of complex ethical, legal and security issues);
– geopolitical (further progress will require international co-operation; increasing global 'digital divide' between developed countries and less technologically advanced countries; use of AI as a military weapon);
– economic (accelerating productivity growth as the population ages (but may come at the expense of increasing income inequality); maintaining the growth trajectory; new products and services (resulting in new professions and businesses); labour market disruptions – jobs consisting of routine labour activities will be vulnerable).

Over the past 5 years, China has invested 750 billion yuan (equivalent to 7 trillion rubles) in AI technologies, and plans to invest another 364 billion yuan (equivalent to 3.3 trillion rubles) in AI in 2023. In Russia, as part of the federal project "Artificial Intelligence", the level of government support has increased significantly, and 24.6 billion rubles will be invested in AI under this programme.

China's experience of comprehensive state support for the development of artificial intelligence is extremely important. At the same time, it is necessary to note the complexity of analysing such experience, as many documents, articles, statistical indicators are formed in Chinese. By 2030, China has set itself an ambitious goal – to become a world leader in the development of artificial intelligence theory and technologies. Thus, China's "Next Generation Artificial Intelligence Development

Plan" (2017) defines three strategic goals for AI development – by 2020, AI technologies and applications should meet the world's advanced level; by 2025, China should make a major breakthrough in the main areas of AI; by 2030, China should take a leading position in the world in the field of artificial intelligence (Circular of the State Council, 2017).

Over the last five years, China has adopted a whole list of various state programmes affecting the development of the artificial intelligence sphere starting from the Plan for the development of next-generation artificial intelligence in 2017;

In the next decade, according to Chinese experts, artificial intelligence and its technologies will catalyse the development of the national economy and create huge advantages for the country when entering new markets (Knox, 2020; Zhao et al., 2022; Xie et al., 2021; Wu et al., 2020). The key areas of AI development in China are shown in Fig. 1 and Table 1. Table 2 shows that China's AI market is actively growing and developing year by year, China is expected to create an industry with a global revenue of RMB 400 billion by 2025. By 2030, AI technology development can add another $ 600 billion to China's economy, thus reaching $ 1 trillion within a decade.

The four key sectors that will create the most economic value from AI adoption in China by 2030 include medicine, automotive, manufacturing and software (Kai et al., 2022). Together, these four sectors could add $600 billion to China's economy by 2030 (Fig. 1). At the same time, the most profitable sector ($380 billion) will be the automotive, logistics, and autonomous driving transport sectors. Two

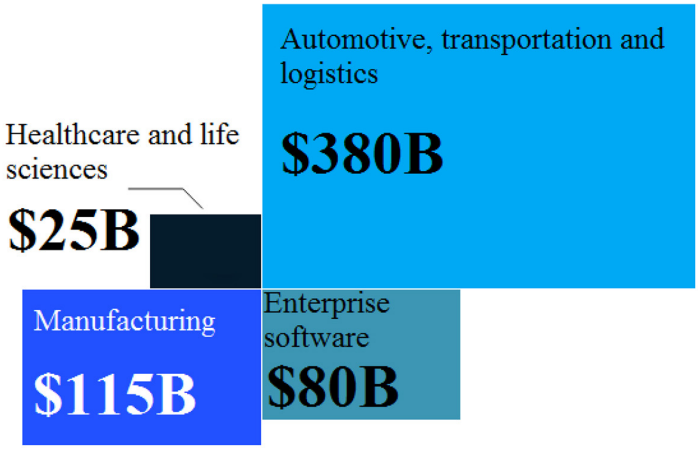

Fig. 1. Four key sectors that will create the greatest economic value from AI adoption in China by 2030

Source: (Kai et al., 2022)

Table 1. Artificial intelligence applications in China, billion yuan

Areas and technologies of AI	2018	2019	2020	2021	2022	2023	2024
Computer vision	23,4	39,1	55,6	84,5	117,3	154,2	205,5
Recommendation systems and intelligent decision support systems	10,9	18,8	26,8	46	68,8	98,4	135,6
Robots	11,6	16,3	22,3	29,4	37,6	46,3	55,5
Speech recognition and synthesis	13,3	19,4	23,3	36,3	49,2	63,5	79,3
Total	59,2	93,6	128	196,2	272,9	362,4	475,9

domains in the manufacturing sector could generate $115 billion in economic benefits (use of digital twins and machine learning). Enterprise software learning companies can generate the most revenue ($80 billion) by providing AI-based solutions to industrial companies (implementation of cloud data warehousing, application of computer vision, language processing). Three areas in the healthcare sector could generate $25 billion in economic benefits (new drug discovery, clinical trial optimisation and support).

Methods and materials

The research base of the study consists of scientific literature, articles and materials of electronic periodicals on artificial intelligence, vacancies and CVs in the field of AI from recruitment agencies, as well as reports of leading technological AI giants. The AI materials were analysed in Chinese.

The study analysed research articles, patents, and dissertations on AI topics in the China National Knowledge Infrastructure (China National Knowledge Infrastructure, 2023) database over the past 10 years (2011–2021). During the analysis it became clear that the list of leading actors who publish on AI topics includes 13 Chinese universities, primarily Tsinghua University and 2 Chinese technology giants "Tencent" and "Baidu ".

The authors' analysis and forecast of the dynamics of investments in the field of artificial intelligence in China showed an increase in financial injections into this sphere by 2.5 times to $39.8 billion by 2030 compared to 2022.

The authors' calculation of the cost of a job in AI showed that the cost of one job is 187.3 thousand yuan per year.

The growth of AI professionals in China will increase 5 times by 2030 compared to 2022.

It is obvious that under similar starting conditions with other countries, China, with competent strategic planning for the long term and large financial injections, already 5 years after the adoption of the fundamental "New Generation Artificial Intelligence Development Plan" in 2017, is breaking into a leading position in the world.

Results and discussion

The number of publications in articles, patents and dissertations on AI in China has increased particularly dramatically over the past 5 years, with a 6-fold increase from 7,276 publications in 2016 to 42 512 publications in 2021, with Chinese tech giant Tencent publishing 1 997 research papers in 2021 alone. The largest amount of funding for China's AI research, according to CNKI, comes from China's National Natural Science Foundation (6 537 research papers supported), China's National Social Science Foundation (3 508 research papers supported), and the National Key Research and Development Programme (1 189 research papers supported). At the same time, publications on AI topics are mainly in academic journals (91 700), patents (36 300) and dissertation materials (24 200).

The priority topics in Chinese articles, patents, and dissertations in the field of AI technologies over the past 10 years have been "robotics", "big data" and "deep learning" (Fig. 2).

Provided that not all papers for 2022 have been indexed in CNKI yet, Tencent already has 1 859 indexed scientific papers in 2022 on the topics of data carriers, electronic devices, data processing methods, image processing methods, and machine learning. The number of Baidu's publications in 2022 exceeds the number of the company's publications for the last 10 years and amounts to 776 papers on similar topics to Tencent.

In 2022, Chinese universities move to the second place, the sharp growth of AI publications is recorded at Chinese technology giants, Tsinghua University moves from the first place to the 4th place (Fig. 3). At the same time, the majority of Chinese technology giants' AI publications in 2022 are patents.

In China, the goal in the coming years is to establish a link between the developers of AI technologies and the manufacturers of products in which these technologies are used, i.e. to commercialise projects as much as possible and focus on the practical application of technologies, all of which will allow China to achieve global leadership already by 2025 in the large-scale application of AI technologies. That is why the main type of scientific publi-

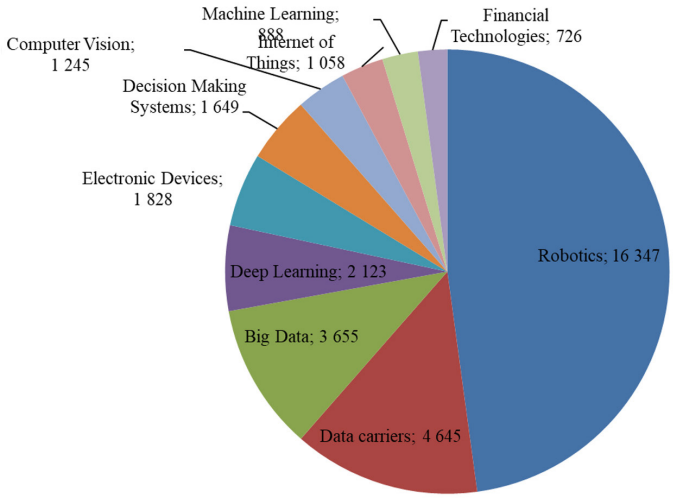

Fig. 2. Key topics of work on AI technology in China, 2011–2021
Source: compiled by authors based on (China National Knowledge Infrastructure, 2023)

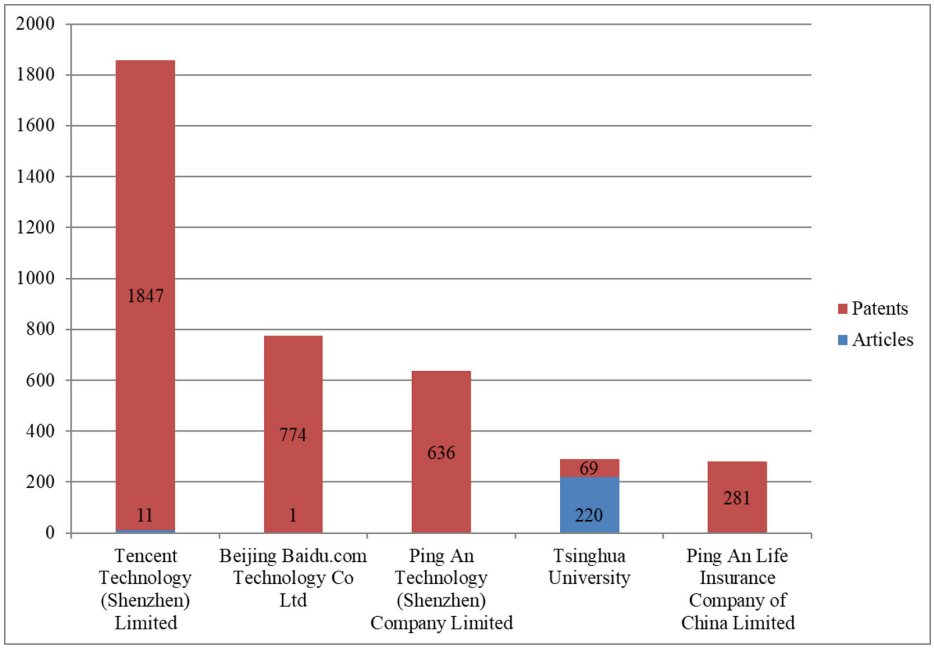

Fig. 3. China's AI research ranking in 2022
Source: compiled by authors based on (China National Knowledge Infrastructure, 2023)

cations in the field of AI in 2022 are patents. For example, Baidu Corporation is leading in the creation of smart cars, and China already has more than 500 smart cities. Another major player in the market, Tencent, is engaged in social networks and games. Since 2016, it has launched an AI lab called "AI Lab", the company is actively investing in a database and information recognition platform called Diffbot, and it conducts big data and AI research based on iCarbonX, CloudMedX, Skymind, and other projects.

China's Tsinghua University is a leader in the field of training AI specialists. The data from Tsinghua University are supported by Chinese statistics on the level of education of students, primarily in the ICT field. The above Chinese statistics show that the number of students studying AI increases with the level of education. The Chinese AI market is actively growing and developing year by year, China is expected to create an industry with a global revenue of 400 billion yuan by 2025. By 2030, the development of artificial intelligence technology could add another $ 600 billion to China's economy, thus reaching $ 1 trillion in a decade. The top-10 sectors with the highest number of graduates in China are dealing with the artificial intelligence graduates (5.16 %) also.

Stanford University's Artificial Intelligence Index Report 2021 notes that the vast majority of specialised academic programmes in AI are taught at undergraduate level, with robotics and automation being the most commonly taught courses in specialised undergraduate and graduate programmes. That said, the report also found that the world's leading universities have increased their investment in AI education over the past four years. The number of courses teaching students how to build or deploy a practical AI model at the undergraduate and graduate level has increased by 102.9 % and 41.7 % respectively. Looking at the educational level – postgraduate level – the proportion of AI PhDs choosing to work in industry has increased by 48 % over the last decade, from 44.4 % in 2010 to 65.7 % in 2019. At the same time, the proportion of new AI PhDs in academia has fallen by 44 %, from 42.1 % in 2010 to 23.7 % in 2019. (Zhang et al., 2022)

Various studies of the likely impact of AI on the Chinese labour market illustrate the difficulty of predicting the impact of AI on the workforce (Zhanga, 2021; Liu et al., 2020). However, we can be absolutely certain that with the strong economic growth and the improvement of AI technology, the list of AI applications in China will expand.

The analysis of AI vacancies posted on the Internet portals of leading Chinese recruitment agencies (51job, taiwan jobs, cn.indeed, China Public Recruitment Network, etc.) allowed us to identify 20 names of AI professions, among which the most popular ones are machine learning engineer (30 %), algorithm engineer (30 %), data scientist (20 %), computer vision engineer (10 %), cloud computing engineer (10 %). Based on the analysis of 1 000 vacancies in these professions, a detailed description of the employer's requirement for the knowledge, skills, abilities of applicants, as well as the required experience and level of professional education was provided. In most cases, China's AI companies require candidates to have a relevant doctoral degree and 3 years of work experience or more.

In Russia, a similar list of in-demand professions in the field of AI with an indication of competences was formed by the Alliance group of companies (Alliance for Artificial Intelligence, 2023). Similar to the Alliance's presented competencies by proficiency level (1 – basic, 2 – advanced, 3 – expert) as well as thematic groups (theory and big data; mathematical modelling and machine learning; working with data), Fig. 4 presents a list of in-demand competencies for the top 5 occupations for Chinese AI professionals.

Analysing the data in Fig. 2 shows that the names of the most in-demand AI occupations in China are different from the Alliance occupations, and the competency sets for these occupations are also different.

The demand for the AI professions indicated in Fig. 4 AI professions are demanded by leading Chinese companies, primarily Baidu, Tencent, Huawei, Alibaba, Sensetime, with monthly salaries starting from 300 000 rubles.

Table 2 shows the educational requirements of Chinese employers for 2 groups of AI employees – Group 1 and Group 2 technical specialists. Group 3 and 4 technicians are not relevant for the AI sector.

In most cases, AI companies in China require candidates to have a relevant doctoral degree. According to IT recruitment agency Zhipin.com, the average salary of Chinese AI specialists in roubles is 260 000 for an algorithm engineer, 260 000 for a machine learning engineer, and 90 000 for image recognition. We emphasise that AI fields such as machine learn-

AI THEORY AND BIG DATA	Machine Learning Engineer	Computer Vision Engineer	Data scientist	Algorithm Engineer	Cloud Computing Engineer
Systems for processing and analyzing large data sets (SQL, NoSQL, Hadoop, ETL, Spark/Hive/HBase ...).	2	2	3	3	2
Microservice architecture	1	1	1	1	3
Smart search	3	2	3	2	2
MATHEMATICAL MODELING, MACHINE LEARNING AND OPTIMIZATION					
Computer Vision	2	3	1	1	1
Knowledge of machine learning and deep learning algorithms such as GBDT, CNN, RNN.	2	3	1	3	1
C/C++ programming language	3	3	3	3	3
JAVA programming language	3	3	3	3	3
Python programming language	3	3	3	3	3
PHP programming language	3	3	3	3	3
Angularjs programming language	2	1	1	1	1
JavaScript programming language	3	3	3	3	3
Nodejs Programming Language	2	1	1	1	1
Open source algorithms and tools such as TensorFlow, Pytorch, TextCNN, LSTM, Transformer, BERT, etc.	2	3	2	3	2
Statistical methods for data analysis	2	2	3	2	2
Virtualized container technologies(experience with Kubernetes, Mesos, Yarn, Docker, OpenStack)	1	1	1	1	3
Text categorization	2	1	1	3	1
Semantic analysis	1	1	1	3	1
Knowledge graph construction	2	1	1	3	1
Software development and testing	3	2	2	2	2
Theory and practice of distributed systems	3	2	2	2	3
Github, Gitlab skills	3	1	1	1	1
DATA HANDLING					
Cloud Computing	3	1	1	1	3
Experience in ML infrastructure development and CPU/GPU memory optimisation.	3	1	1	1	1
Data fabric	1	1	3	1	1
Business Reference	1	1	3	1	1

Fig. 4. Lists competencies in the most sought-after AI occupations in China, 2022

Source: compiled by authors

Table 2. AI salary range and education requirements in the Chinese labour market, 2022

AI area	Average salary in roubles per month in China	Requirements for a Group 1 technician	Number of vacancies, technical specialists of 1 group, th.	Requirements for a Group 2 technician	Number of vacancies, Group 2 technical specialists, th.
Fundamental research in the field of machine learning	260 000	Doctoral degree	10.111	Master's degree	0.433
Data Scientist	220 000	Doctoral degree	7.658	Master's degree	0.327
Algorithm researcher	260 000	Doctoral degree	4.021	Master's degree	-
Researcher of image recognition algorithm	90 000	Doctoral degree	2.685	Master's degree	0.158

Source: compiled by authors based on (BOSS Direct Recruitment, 2023)

ing and data processing are the most in demand on the Chinese labour market.

Conclusion

China's Artificial Intelligence Strategy Documents (2017) determined that by 2025, China will establish an AI industry with a global revenue of 400 billion yuan, make major breakthroughs in priority AI technologies, and become the world leader in AI application development by 2030.

The main frontier challenges in AI technologies in China are concentrated in the field of computer vision. Over the past 5 years, China has invested 750 billion yuan (equivalent to 7 trillion rubles) in AI technologies, and plans to invest another 364 billion yuan (equivalent to 3.3 trillion rubles) in AI in 2023. It is expected that the most profitable sector of the Chinese economy in AI will be the automotive, logistics, and autonomous driving transport sector, which will reach $ 380 billion by 2030.

China ranks second to the US in terms of the proportion of top scientists and overall AI talent. Chinese AI professionals are highly mobile. For example, there are 12 % more Chinese AI professionals working in the US than in China. Chinese students actively choose to study in the ICT sector, and the higher the level of education (master's/doctoral), the more popular the choice of educational programmes in the field of artificial intelligence becomes.

An analysis of vacancies from leading Chinese recruitment agencies (51job, taiwan jobs, cn.indeed, etc.) and the lists of the most in-demand AI professions and competences formed on this basis showed that highly qualified specialists with knowledge of the Python programming language, knowledge of SQL DBMS and a PhD degree are in high demand in Chinese companies – their salaries start from 300,000 roubles in the Russian equivalent per month. In most cases for these professions, Chinese AI employers require a PhD and 3 years of work experience. An analysis of the salary levels of Chinese and Russian AI specialists in the most in-demand AI professions showed that they do not differ significantly.

Thus, under similar starting conditions with other countries, China, with its competent strategic planning for the long term and large financial injections, is already 5 years after the adoption of the fundamental "New Generation Artificial Intelligence Development Plan" in 2017, breaking into a leading position in the world.

China's experience in integrated planning and state support for the development of the artificial intelligence sphere is extremely important and in demand in the context of transferring the competence model of the Chinese AI specialist to the Russian high-tech segment of the labour market.

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