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A Review on the Measurement and Economic Effects of Artificial Intelligence

Jinfeng Ou

[1] School of business, Lingnan Normal University, Zhanjiang 524048, Guangdong, China

[2] Guang Dong Coastal Economic Belt Development Research Center, Lingnan Normal University, Zhanjiang 524048, Guangdong, China.

Abstract

The development level and economic effects of artificial intelligence have become a hot topic of high concern in the academic community. This article aims to comprehensively review the relevant literature on the measurement of the development level of artificial intelligence and its economic effects from an economic perspective. Based on a clear definition of the concept of artificial intelligence, it summarizes the measurement methods for the comprehensive development level of artificial intelligence, and explores the impact of artificial intelligence on economic growth, labor employment, and income distribution, Strive to provide valuable experience and theoretical reference for the measurement of the development level of artificial intelligence and the study of economic effects.

Keywords

Artificial Intelligence; Development Level; Measurement Research; Economic Effects.

1. Introduction

Driven by new theories and technologies such as mobile internet, big data, super-computing, sensor networks, and brain science, artificial intelligence has accelerated its development, presenting new features such as deep learning, cross-border integration, human-machine collaboration, open group intelligence, and autonomous control. It is having a significant and profound impact on economic development, social progress, global governance, and other aspects. In this context, various countries or regions have placed the development of artificial intelligence in an important strategic position, formulated artificial intelligence development strategies, and seized the initiative and discourse power of artificial intelligence development, in order to seize the opportunity in the new round of international industrial division of labor adjustment and interest game. The permeability, substitutability, and synergy characteristics of artificial intelligence will profoundly change traditional production methods, spawn a series of new industries, formats, and models, improve production efficiency and factor allocation efficiency of industrial departments, and promote the optimization and upgrading of industrial structure. Artificial intelligence belongs to an emerging research field and has always received widespread attention from the academic community. At present, the academic community mainly explores the concept and connotation of artificial intelligence, its measurement, and its effects on themes such as economic growth, labor employment, and income distribution. This article comprehensively reviews and explores relevant literature around the above themes, attempting to provide reference and reference for the measurement and economic effects of artificial intelligence research.

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2. The Conceptual Connotation of Artificial Intelligence

The origin of Artificial Intelligence was at the Dartmouth Summer Artificial Intelligence Research Program Seminar. At this conference, Artificial Intelligence was first proposed and gradually developed into a discipline. Oxford English Dictionary defines "Artificial Intelligence" as the theoretical science of computer systems capable of performing tasks that typically require human intelligence. Artificial intelligence has shown a trend of intersecting and integrating with different disciplines, and has been widely applied in fields such as intelligent control, intelligent manufacturing, intelligent retail, image recognition, genetic programming, etc. It has become a strategic new technology leading a new round of technological revolution and industrial transformation.

The academic community has not yet reached a consensus on the concept and connotation of artificial intelligence, and research is mainly conducted from two aspects: technology and application. From a technical perspective, artificial intelligence is the cognitive science of intelligent computer programs, belonging to a branch of computer science [1], including machine learning, deep learning, deep neural networks, natural language processing, computer vision, speech recognition, and other content. Taddy (2017) proposed that artificial intelligence consists of Domain Structure, Data Generation, and General Purpose ML [2]. Brynjolfsson et al. (2017) proposed that artificial intelligence is the ability of machines to imitate intelligent human behavior or the ability of intelligent agents to achieve goals in complex environments, emphasizing the development of intelligent agents brought about by advances in computer technology and endowing them with the ability to learn independently, make decisions, and other human behaviors [3]. From the perspective of application connotation, the academic community regards artificial intelligence as a general-purpose technology similar to steam engines and computers, highlighting the high integration of "technical attributes" and "social attributes", especially the deep integration of artificial intelligence with different industries, gradually forming an intelligent economic form of data-driven, human-machine collaboration, cross-border integration, and co creation and sharing. He Yuchang and Zong Sujuan (2017) proposed that artificial intelligence is a highly developed product of productivity in the era of information industrialization. Artificial intelligence technology and its applications have driven the rise and development of the intelligent economy, which is an organic unity of intelligent industries, intelligent enterprises, and intelligent labor [1].

3. Research on Measuring the Development Level of Artificial Intelligence

3.1. Application of Industrial Robots

Industrial robots are an important component of manufacturing technology in intelligent manufacturing systems [4], and are also the main way for intelligent technology to be applied to the manufacturing industry. Scholars use the application of industrial robots as a proxy variable for the comprehensive development level of artificial intelligence [5]. On this basis, the academic community further subdivides the application indicators of industrial robots into indicators such as the stock of industrial robots [6-8], the import of industrial robots [9-10], the input of industrial robots [11-12], the annual change in the scale of industrial robots [13], the application density of industrial robots [14], and the total trade volume of industrial robot products [15]. In terms of data, there are two main sources of basic data for industrial robots: the International Federation of Robotics industrial robot database; The second is the statistical data on industrial robots from the National Bureau of Statistics. Due to the collection of industrial robot shipments, stocks, and usage densities by industry from nearly 50 countries or regions worldwide in the past two decades, the Industrial Robot Database of the International

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Federation of Robotics covers 90% of the installation information in the global industrial robot market. This database is widely used by academia.

3.2. Patent for Artificial Intelligence Technology

Technology patents, as the most explicit output indicator of knowledge creation and technological progress, are often used to reflect the scientific development level and the latest technological trends of a country or region. Artificial intelligence has a highly knowledge intensive characteristic, and scholars use AI technology patent indicators to measure artificial intelligence. Fujii&Managi (2018) studied the development trends of artificial intelligence technology inventions and the key directions for research and innovation based on global artificial intelligence patent data [16]. Zhang Zhengang et al. (2018) identified and analyzed the development trend of cutting-edge artificial intelligence technology based on patent econometric analysis [17]. Chen Jun et al. (2019) conducted a comparative study on the development of the artificial intelligence industry in China and the United States based on patent data, including the overall situation of patent applications, PCT patent applications, key technical areas of IPC, and innovative entities. The results showed that the artificial intelligence industry in China and the United States is in a synchronous development stage [18]. Zhao Rongying et al. (2019) used patent measurement and forward citation indicators to analyze patent data in the field of artificial intelligence, in order to clarify the technological hotspots, competitors, technological development paths, and trends of artificial intelligence [19]. Wang Yawei et al. (2019) used patent analysis methods to identify and compare the technological innovation paths of China's artificial intelligence industry from three dimensions: core technologies of artificial intelligence, patent citation networks, and patent commercialization [20]. Qian Xiaojing and Zhou Wenhui (2021) used the PATENTHUB global patent database to calculate the proportion of "artificial intelligence" patent authorization to the total patent authorization to measure the new generation of artificial intelligence [21].

3.3. Development Level of Artificial Intelligence Industry

The literature mainly revolves around the perspectives of industrial intelligence and intelligent industrialization, and constructs an indirect form of industrial competitiveness index to measure artificial intelligence. Industrial intelligence mainly refers to the empowerment of artificial intelligence technology in the industry, which in turn leads to an increase in output and an improvement in production efficiency, especially in the transformation and upgrading of the manufacturing industry. Intelligent industrialization refers to promoting the industrialization or commercialization of artificial intelligence technology achievements, such as the commercial application of artificial intelligence technology in the fields of computer vision, speech recognition, and natural language processing. Industrial robots are an important foundation for the intelligent transformation of the manufacturing industry, and the development level of the industrial robot industry has become a key factor in measuring the intelligence of a country's manufacturing industry. Liu Yuan et al. (2017) analyzed the development trend of China's industrial robot industry from four dimensions: market size, industrial layout, technological level, and development trend [22]. Zhang Wanli and Xuan Yang (2020) constructed an indicator system consisting of seven dimensions: intelligent instrument equipment, software usage, robotics, data processing, information platform maintenance, information collection, and intelligent technology innovation. Principal component analysis was used to measure the level of industrial intelligence in China [23]. Li Jianxuan (2020) constructed an evaluation index system for the degree of intelligence in China's manufacturing industry from three levels: intelligent technology, intelligent applications, and intelligent benefits [24]. Liu Jun et al. (2021) proposed constructing an indicator system to measure the intelligence index from the basic input layer, production application layer, and market benefit layer [25]. In addition, some scholars have further expanded the breadth and depth of research

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data. Zhao Chenyu (2021) used text mining technology to construct an enterprise level digital development index [26].

3.4. Comprehensive Evaluation Index System

A single indicator measuring the comprehensive development level of artificial intelligence may have certain one-sidedness and cannot truly reflect the comprehensive development level of artificial intelligence. Therefore, some scholars have attempted to construct a multi-dimensional indicator system to measure the comprehensive index of artificial intelligence. Sun Zao and Hou Yulin (2019) constructed a measurement index system for industrial intelligence, which mainly includes three dimensions: infrastructure construction, production application, competitiveness and effectiveness. It involves 10 detailed indicators such as software popularization and application, intelligent manufacturing industry situation, and industrial enterprise innovation ability [27]. Zhao Fang and Liu Yujia (2020) constructed an evaluation index system for the comprehensive development of artificial intelligence from the perspective of input-output. The investment in artificial intelligence was measured by three indicators: human investment, financial investment, and material investment. The output of artificial intelligence was measured by two indicators: economic output and product output [28]. Previous research has mainly focused on the development and changes of the artificial intelligence industry itself, with little consideration given to the economic and social environmental factors in which the industry operates. Some scholars have further expanded in this regard. Lv Rongjie and Hao Lixiao (2021) calculated the comprehensive index of inter provincial artificial intelligence in China from 2003 to 2018 from four dimensions: institutional environment, infrastructure, technological innovation, and production application [29]. Gu Guoda and Ma Wenjing (2021) constructed a comprehensive evaluation index system for artificial intelligence with "environmental support, knowledge creativity, and industrial competitiveness" as the main evaluation areas [30].

3.5. Other Measurement Methods Or Indicators

Overall, the above four methods are mainly based on the macro level and pay less attention to the micro entities of the enterprise. To this end, scholars use case studies, text mining and other methods to conduct research on unformatted texts such as enterprise annual reports or government documents, in order to measure artificial intelligence. For example, Zhao Chenyu (2021) used text mining methods to measure the digital development level of listed companies, and counted the number of keyword disclosures from four aspects: digital technology applications, internet business models, intelligent manufacturing, and modern information systems, thereby obtaining the total digital development index of manufacturing listed companies [26]. In addition, some scholars consider artificial intelligence as a production factor and calculate the material capital of the artificial intelligence industry to measure the comprehensive development level of artificial intelligence. For example, Shen Shang (2020) chose the amount of fixed assets investment in information transmission, software and information technology services to indirectly measure AI [31]. However, Brynjolfsson et al. (2017) argue that measuring the comprehensive development level of artificial intelligence using the amount of artificial intelligence capital may result in significant measurement errors, as the output of artificial intelligence capital is mostly intangible and cannot be accurately measured, and artificial intelligence capital has strong technology spillover effects, making it more difficult to measure the complementary investment caused by this [3].

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4. Research on the Economic Effects of Artificial Intelligence

4.1. Artificial Intelligence and Economic Growth

The impact of artificial intelligence on economic growth is a continuation of the impact of automation technology on economic growth[32]. The impact of technological progress on economic growth is a focus of academic research. Scholars view artificial intelligence as the latest form of automation technology development and explain the growth effect of artificial intelligence automation through economic growth models. Representative literature such as Zeira (1998) [33], Acemoglu&Restrepo (2016) [6], Cheng Wen (2021) [34], and Chen Yanbin et al. (2019) [35]. Acemoglu&Restrepo (2016) introduced a frequently substituted elastic production function to internalize automation and task count. Research has found that the development of automation technology first manifests as the substitution of capital for labor, and the substitution effect will reduce the demand for labor in the market; At the same time, the creation of new tasks will also bring production effects, further increasing the demand for labor force, which can be used for new tasks in production[6].

Can artificial intelligence promote economic growth? There are two distinct voices in the academic community regarding the answer to this question. Technological optimists believe that artificial intelligence, as a major technological change, can improve productivity levels and promote economic growth. However, technological pessimists argue that artificial intelligence cannot lead to breakthrough economic growth, and the growth effect of technological advancements in artificial intelligence cannot be reflected in statistical data. The effect of technological advancements in artificial intelligence is overestimated, and artificial intelligence faces questioning of the "productivity paradox". For this reason, Brynjolfsson et al. (2017) provided a comprehensive explanation from four dimensions: firstly, the erroneous expectation that the technological progress effect of artificial intelligence was indeed overestimated; The second is measurement error, which refers to the erroneous measurement of artificial intelligence output or productivity by researchers; The third is centralized allocation and rent dissipation, which means that artificial intelligence has only improved the productivity level of a few star enterprises, and the progress of artificial intelligence technology has brought about a significant "digital divide", resulting in market distortion and a decrease in overall social productivity; The fourth is the lag in execution and reconstruction, which means that the implementation and application of artificial intelligence technology need to be based on relevant technological support, infrastructure, and organizational structure adjustment [3].

The academic community conducts empirical analysis on the impact mechanism of artificial intelligence and economic growth. Chen Xiao et al. (2020) found that industrial intelligence has a significant positive impact on the quality of economic growth based on inter provincial panel data [36]. Yang Guang and Hou Yu (2020), based on data on the use of industrial robots, concluded that the use of robots does indeed have a promoting effect on economic growth, and total factor productivity is an important transmission mechanism for the impact of industrial robots on economic growth [37]. Fan Xiaonan et al. (2020) [38], Zheng Qiongjie and Wang Gaofeng (2021) [39], Liu Liang and Hu Guoliang (2020) [40] have reached similar conclusions based on data from Chinese manufacturing companies. Cheng Chengping and Chen Zhi (2021) empirically concluded that artificial intelligence can promote economic growth through replacing labor factors, human-machine integration, and the expansion of the artificial intelligence industry chain. It can also indirectly promote economic growth by improving human capital levels, improving technological innovation efficiency, market efficiency, and government governance efficiency [41]. In terms of implementation paths, the academic community focuses on labor or human capital, and achieves high-quality economic development by improving the quality of labor or human capital. He Xiaogang et al. (2020) explained the micro mechanism of the effect of human capital structure on improving

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information technology productivity based on the complementary theory: high skilled labor can effectively match the production mode and organizational structure changes brought about by the application of information technology [42]. Chen Xiao et al. (2020) proposed that industrial intelligence mainly helps improve the quality of economic growth through high and medium skilled labor force; The implementation path is to increase the demand for higher skilled labor force and replace medium skilled labor force, and achieve the upgrading of employment structure to improve the quality of economic growth [36].

4.2. Artificial Intelligence and Employment

The development of artificial intelligence, on the one hand, improves productivity levels, and on the other hand, it can also trigger the phenomenon of "machine replacement", which leads to technical unemployment. Currently, there is a large amount of literature on the impact of artificial intelligence on labor employment, with representative literature including Autor et al. (2003) [43], Acemoglu&Restrepo (2016) [6], Wang Xiaoxia and Li Lei (2020) [9], Wu Liyuan et al. (2023) [44], Wang Qianyuan et al. (2022) [45], Wang Linhui et al. (2022) [46], etc. From existing literature, it can be seen that artificial intelligence may have two completely different impacts on the labor market at the same time: one is the substitution effect, which means that artificial intelligence leads to machine replacement, and industrial machines will replace a large number of low-skilled labor, thereby reducing social employment opportunities; The second is the creation effect, which means that the development of artificial intelligence will bring about economic expansion, promote industrial transformation and upgrading, and change in social production methods. The new industries, new formats, new models, new products, etc. derived from this will enhance the market's demand for highly skilled labor and generate the creation effect of new job opportunities. Therefore, artificial intelligence has a significant skill bias towards the labor market structure, and there is no consensus in the academic community on which effect plays a dominant role.

4.3. Artificial Intelligence and Income Distribution

Artificial intelligence, as a biased technological advancement, not only promotes economic growth and increases social wealth, but also affects the structure of the factor market and has a biased impact on the share of factor income [47]. Historical experience has shown that every major technological advancement will have an impact on the labor market, and the technological dividends accompanying the development of artificial intelligence may exacerbate the polarization of social wealth distribution, with a large amount of wealth concentrated in the hands of a few people. The biggest challenge faced by the development of artificial intelligence is the issue of income distribution, mainly manifested in the income distribution of different factors and the income gap caused by the income distribution of heterogeneous workers. At present, scholars mainly explore three aspects: the impact of artificial intelligence on changes in factor income share, the impact of artificial intelligence on different labor income distributions, and related public policies. Firstly, the academic community regards artificial intelligence as the latest stage of automation development. Artificial intelligence has dual attributes of technology and capital. The automation of production methods is actually a process of "machine replacement", which constantly replaces labor with capital. In this process, the share of capital input will increase. The widespread application of artificial intelligence will continuously increase the income share of capital elements, correspondingly reduce the income share of labor, leading to more wealth flowing to capital owners and exacerbating the degree of inequality in social income distribution. Secondly, artificial intelligence has a heterogeneous impact on the income of different labor forces. Low skilled labor engaged in routine and programmed tasks will be replaced by automated robots, and the number of jobs for low skilled labor will continue to decrease. The significant decrease in production costs brought about by automated production in enterprises will to some extent

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squeeze the wage compensation of low skilled labor, thereby reducing the actual income of low skilled labor. Finally, the bias of artificial intelligence technology has led to a further widening gap in the income share of workers with different elements and skills, which has attracted widespread attention from both academia and policy levels. In order to enable the entire society to enjoy the technological dividends brought by the development of artificial intelligence, some scholars propose that government departments should make policy adjustments based on specific circumstances to alleviate the negative impact of artificial intelligence on the labor employment market and income distribution. For example, clarifying data property rights and promoting fair competition among enterprises; Strengthen labor education and training to meet the job needs of new positions, etc. [48].

5. Conclusion

Existing literature has conducted in-depth research on topics related to the new generation of artificial intelligence and industrial structure optimization, and has achieved relatively comprehensive research results. Specifically, it mainly includes the following points. Firstly, existing literature has explored the connotation of artificial intelligence and applied different methods to measure it. The new generation of artificial intelligence is the cognitive science of intelligent computer programs, mainly including machine learning, deep learning, natural language processing, computer vision, and so on. At the same time, artificial intelligence is a strategic general-purpose technology with significant skill, capital, and data biases. Artificial intelligence will profoundly change traditional production methods, generate biased substitution for labor factors, and change innovation or knowledge creation processes. There is still no consensus in the academic community on the measurement methods of artificial intelligence, and research is mainly carried out from aspects such as industrial robots, artificial intelligence majors, artificial intelligence industries, and comprehensive evaluation index systems. Different measurement methods or proxy variables have their own characteristics and can reflect the comprehensive development level of artificial intelligence from different perspectives, laying an important foundation for subsequent research. Secondly, literature has studied the impact of artificial intelligence on economic growth, labor employment, and income distribution. In theoretical modeling analysis, some literature views artificial intelligence as the latest stage of automation, while others approach it from a biased perspective of technological progress, viewing it as a labor-intensive or capital enhancing technology. In terms of empirical research, scholars mainly choose proxy variables such as "industrial robots" and "artificial intelligence technology patents" to measure the comprehensive development level of artificial intelligence, and use methods such as econometric analysis to conduct empirical analysis.

On this basis, further research needs to be expanded around the following two points. One is to improve the scientific measurement of the development level of artificial intelligence. The literature mainly uses explicit indicators such as the usage of industrial robots, the application density of industrial robots, and the number of artificial intelligence patents as proxy variables for the comprehensive development level of artificial intelligence. The advantage of this measurement method is that it is simple and feasible, but using a single indicator may underestimate or overestimate the comprehensive development level of artificial intelligence, leading to biased research conclusions. Subsequent research needs to further clarify the construction ideas of the indicator system, select a more scientific measurement indicator system, measure the comprehensive development level of artificial intelligence in multiple dimensions, and characterize its regional differences. The second is to explore the economic effects of artificial intelligence from both theoretical and empirical perspectives based on scientific measurement of the development level of artificial intelligence, and combine the

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characteristics of the economic effects of artificial intelligence to propose policy recommendations to promote the healthy development of artificial intelligence.

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