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THE MACROECONOMIC IMPACTS OF ARTIFICIAL INTELLIGENCE-SUPPORTED DIGITAL TRANSFORMATION AS THE CONTEXT OF INDUSTRY 4.0 AND SOCIETY 5.0

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ABSTRACT

Some technological innovations have not only made daily life easier; they have also led to fundamental transformations in production methods. With the change in the structure of production, the emergence of industrialization stages has also become possible. This process, which began with Industry 1.0, has affected the economic and social structure in a multidimensional way at every stage. With the transition to Industry 4.0, the production structure and industrial organization are being reshaped, and this transformation is producing various macroeconomic results. The aim of this study is to analyze the possible effects of Industry 4.0 and the anticipated Society 5.0 on macroeconomic variables in the short, medium, and long term. The analysis is approached from the perspective of developed, developing, and less developed countries. The study evaluates the effects of these transformations, particularly on economic growth, employment, income distribution, development gaps, and capital and labor factors. The findings indicate that Industry 4.0 and Society 5.0 may have negative effects on the labor market, income distribution, and development disparities in the short term; however, they show a positive impact on economic growth.

KEYWORDS: Industry 4.0, Society 5.0, Artificial Intelligence, Employment, Technological Transformation.

1. INTRODUCTION

Throughout history, there have been many developments that have made human life easier. However, some inventions that changed the production process and structure have had a greater impact globally than others. Changes in production technology that gave rise to industrial stages have led to significant quantitative increases in production. The Industrial Revolution 1.0 phase began with the use of steam energy in production and the first step towards factory-style production from hand-operated looms. The increase in production that emerged during this phase contributed significantly to the growth of countries and also ensured the development of international trade. The discovery of new energy sources, the development of new production techniques, and their introduction into production facilitated the transition to subsequent stages of industrialization. During the industrial revolutions, technological innovations in other fields, in addition to those specific to industry, played a complementary and accelerating role in production processes. At each stage, the level of mechanization in production processes increased, and this development expanded industrial production capacity while also leading to a reshaping of the differences in development between countries.

The first industrial revolution utilized water and steam power to mechanize production, the second industrial revolution employed electrical energy to establish mass production, and the third industrial revolution utilized electronic and information technology to automate production. In the Fourth Industrial Revolution, rather than the emergence of a new type of energy, digitalization and robotization are taking the connections between the virtual world and the physical world to a much higher level. While the first three industrial revolutions emerged spontaneously as a result of technological developments, the future of the Fourth Industrial Revolution was announced in advance at a fair held in Hannover, Germany.

Industrial revolutions have produced multidimensional outcomes that affect not only production processes but the entire economic structure. In this context, Industry 4.0 and the anticipated Society 5.0 are also expected to have significant impacts on macroeconomic variables through technological transformation channels. In particular, the proliferation of digitalization, automation, and artificial intelligence-based production processes has the potential to reshape economic growth dynamics, income distribution, wage structures, and the functioning of the labor market in the short, medium, and long term. This study aims to analyze the potential effects of Industry 4.0 on the aforementioned macroeconomic factors within an analytical framework and to discuss the possible outcomes. Furthermore, it seeks to answer the question of whether this transformation process yields symmetric or asymmetric outcomes for developed and developing countries, thereby assessing the potential effects of Industry 4.0 on global economic balances.

2. THE HISTORICAL FRAMEWORK OF TECHNOLOGICAL TRANSFORMATION: STAGES OF INDUSTRIALIZATION

Until the beginning of industrialization, the economic structure in the world was primarily rooted in agriculture and livestock, with handicrafts; however, with the emergence of the first industrial revolution, this began to change. The labor-based economic structure gradually gave way to a mindset focused on mechanization and mass production. As the production structure changed, production increased, and as the number of producers and consumers rose, trade volume grew steadily.

Historically, three major industrial revolutions have profoundly transformed production. Currently, a new phase known as Industry 4.0 has emerged, influencing humanity's future.

Table 1: Basic Features of the Industrial Revolutions.

Period	Period of Transition	Energy Source	Main Technical Success	Main Advanced Industry	Transportation Vehicles
I: 1760-1900	1860-1900	Coal	Steam Engines	Textile and Steel	Train
II: 1900-1960	1940-1960	Oil-Electricity	Internal Combustion Engines	Metalurgy, Automobile, Machine	Train, Road Vehicle
III: 1960-2000	1980-2000	Nuclear Engery-Natural Gas	Computers and Robots	Manufacturing	Road Vehicle, Airplane
IV: 2000-2010	2000-2010	Green Energy	Internet, 3D Printer, Genetic Engineering	High Technology Industries	Electric Car, Ultra High-speed Trains
V: 2010-	2010-2020	Energy,	Drones, Cloud, Big Data, Bio-tech Quantum PCs	Information, Communication Technologies	Drone Vehicles, Airspace Vehicles

Kaynak: Prisecaru, 2016: 57; Perez, 2002: 20; Perez, 2010.

A paradigm emerges through an implicit social agreement based on factors such as the technological capability of the product, market acceptance, functional consistency, and other factors that contribute to the value of the service or technology. Microprocessors, which are produced with the expectation of becoming faster, smaller, more powerful, digital, and increasingly affordable over time, contrast with the 1950s and 1960s when it was accepted that cars and airplanes were becoming larger. On the other hand, the continuous expectation of multifunctionality in digital products was not present in cars and airplanes; instead, fulfilling their basic functions was considered important. (Kuhn, 1962; Perez, 2010).

The technological revolution generally creates a significant leap in the economy's ability to generate wealth. Thanks to the revolution, a broad chain of innovations forms, leading to effects that increase the efficiency and effectiveness of all sectors and fields of activity. Technologies emerging during this period, along with certain infrastructure and organizational principles, are integrated into society's use. With the revolution, there are also jumps in the dissemination processes of technological and economic paradigms and in productivity increases (Perez, 2002: 20; Perez, 2010).

2.1. Industry 4.0

Previous industrial revolutions emerged spontaneously as a result of inventions that changed the structure of production. The most fundamental feature that distinguishes Industry 4.0 from other industrial revolutions is that its basic elements and the methods it will use were announced to the world in a report before it even emerged. Industry 4.0 was announced to the public at the Hannover Fair in Germany in 2011 (Kagermann et al., 2013). The key elements of Industry 4.0 include cyber-physical systems, the Internet of Things (IoT), big data, cloud computing, dark factories, 3D printers, augmented reality, and robotic technologies. Programmable Logic Controllers (PLCs) in Industry 3.0 have been replaced by Programmable Automation Controllers (PACs) and Industrial PCs (IPCs) in Industry 4.0. Thus, production systems with computer infrastructure carry out production by exchanging information with each other via the internet or network connections. Each component within the production line connects to each other and the central operator via the network, enabling speed and flexibility in production, resulting in cost reductions and increased competitiveness. This represents the next stage of automated production. Furthermore, a new production style is emerging where consumers are in direct contact with producers during the production process. Both the production and sales stages have a more integrated structure.

In Industry 4.0, technological elements are increasingly integrated into production, aiming to redesign the production process. The goal is to adopt a flexible production style and use resources more efficiently in order to meet increasingly diverse and growing customer demand. Smart factories are being created to achieve these goals. In these smart factories, each component in the production process can communicate with each other (Internet of Things) and direct the production process by retrieving the data it needs from cloud computing.

Industry 4.0 places particular emphasis on robotization in manufacturing. It is noted that a new phase is emerging where robots are increasingly utilized in production. Furthermore, alongside Industry 4.0, new types of factories are emerging that incorporate flexible collaborative robots, known as “cobots.” Thus, it is not considered feasible to completely eliminate the human factor from production (Kolbeinsson et al. 2019). Collaborative robots (Cobots) are designed to work alongside humans in the production process and assist them. Businesses are increasingly using collaborative robots (Cobots) because they can be placed next to people on small assembly lines. (Calitz et al. 2017; Kadir et al. 2018). This situation, referred to as Human-Robot Collaboration (HRC) within the scope of Industry 4.0, describes a complex arrangement between humans and non-human elements (machines, robots, software, etc.) in the production process. As Industry 4.0 becomes increasingly adopted, manufacturers may not find human labor as attractive as robots, cobots, and networked technologies. Robots may be preferred by large companies, while cobots may be preferred by SMEs. The use of cobots in industries is still limited, has not created a comprehensive transformation, and is used in areas where human-robot collaboration is easy. Humans and cobots should be seen not as separate entities but as human and non-human actors on the same network (Weiss,et al. 2021). A study by MIT (2015) showed that when humans and cobots work together, productivity increases by 85% compared to when humans or cobots work alone.

In the Industry 4.0 process, the use of technology, robotization, and computerization in production will be more intensive. This will ensure a more optimized production process. Other advantages of Industry 4.0 include shorter timelines for new product launches, improved customer response, allowing for customized mass production without a significant increase in production costs, a more flexible work environment, and more efficient use of natural resources and energy.

2.2. Society 5.0

The concept of Society 5.0, like Industry 4.0, was introduced at a trade fair in Hanover, Germany. Just as Industry 4.0 was announced at a trade fair in Hanover, Germany in 2011, Society 5.0 was announced by Japanese Prime Minister Abe at the CeBIT technology fair in Hanover, Germany in 2017, and has since generated public awareness. The Society 5.0 concept is sometimes also referred to as Industry 5.0. Society 1.0 is described as a hunter-gatherer society, Society 2.0 as an agricultural society, Society 3.0 as an industrial society, Society 4.0 as an information society, and Society 5.0 as a super-smart society.

The concept of Society 5.0 was formally proposed in Japan's 5th Basic Science and Technology Plan in 2016 and approved by a Cabinet Decree. Since then, the Japanese government has been supporting Society 5.0, a vision to create a human-centered, sustainable society by enhancing human productivity and quality of life through cyber-physical systems (Fukuda, 2019). Society 5.0 is based on the idea that society is at the center of industry. It views technological advancements and the improvements in production processes brought about by Industry 4.0 as a driving force.

The goal of Society 5.0 is to create a human-centered society where certain social and economic problems are solved and people's well-being is enhanced. In the Society 5.0 concept, digitalization is a tool, people are the central actors, and economic growth and technological development exist for the welfare of the whole society, not just a minority. To achieve this, it is necessary to create a synthesis between cyberspace and the real world (physical space), collect data, and generate new solutions based on this data (Harayama, 2017; Fukuyama, 2018).

Society 5.0 is essentially focused on making greater use of new technologies that are components of Industry 4.0, such as artificial intelligence (AI), cyber-physical systems, robots, 3D printers, cloud computing, big data, and the internet of things (Calp ve Bütüner, 2022; Lobe, 2017). This aims to accelerate economic development and improve the quality of life. Both involve the use of cyber-physical systems. While Industry 4.0 aims to create new value and minimize production costs, Society 5.0 aims to create a super-smart society (Deguchi, 2020:19). Smart societies will be able to use new technologies more effectively and in their own best interests (Calp and Bütüner, 2022). Therefore, Society 5.0 aims for a super-smart society by centering on Industry 4.0.

2.3. Industry 4.0 and Society 5.0: Structural Impacts for Developed and Developing Economies

Gerschenkron (1962) chose the industrialization process as the dependent variable, stating that the degree of backwardness is its explanatory variable. Based on the trend in the growth rates of countries, he stated that the "degree of backwardness" is related to the intensity and duration of industrial spurts, the share of investment goods in newly developing industrial production, the average factory scale, changes in consumption levels, changes in the productivity of agricultural labor, and the rate of increase in industrial goods' purchases of agricultural products. He categorized countries at the beginning of the industrialization process into two groups: economies that showed a distinct spurt and economies that could not achieve a spurt despite the existence of all the necessary elements for a spurt, thus missing the opportunity.

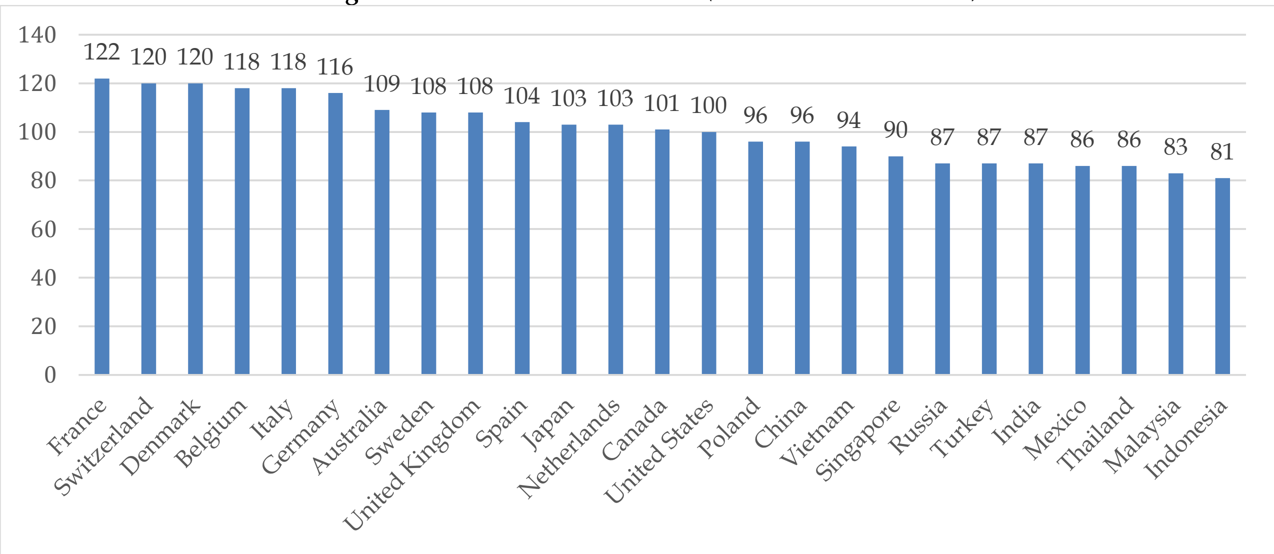
Countries that enter the industrialization process progress much faster than other countries from the moment they begin to make a leap in this area. Such a leap can only occur under the following conditions (Şahinkaya, 1999: 22):

1. The existence of effective demand that will prevent the formation of a production surplus
2. The existence of institutions that will convert the savings surplus into capital
3. The use of capital-intensive technologies due to the shortage of skilled labor
4. Emphasis on the production of capital goods

The first industrial revolution originated in England and spread throughout Europe. The second industrial revolution spread rapidly, particularly in America and Japan. Consequently, these two revolutions widened the gap between developed and underdeveloped countries. The third industrial revolution, however, expanded further to other parts of the world through international corporations, creating opportunities for developing countries to close this gap.

The industrial value share of developing countries such as China, India, and Brazil reached €6.577 billion and 40% in 2011, an increase of approximately 179% compared to 1990. In contrast, during the same period, the industrial value share of Western European countries decreased by 8% in Germany, 20% in France, and 29% in the UK. These problems have led to reductions in labor costs in production, shorter product development times, and more efficient use of resources (Qin, v.d, 2016: 173). Therefore, it can be said that the decline in the industrial value share experienced by developed countries during this process, and the negative consequences it created, are one of the factors that gave rise to Industry 4.0. In this context, developed countries see Industry 4.0 and its implications as a way out to regain the competitive advantage they lost to developing countries at the end of the 20th century. It is believed that Industry 4.0 can enable developed countries to regain the competitive and production advantage they lost in the past.

Figure 1: Production Cost Index (2014 = 100 in America).



Source: Boston Consulting Group (BCG).

Over the past 25 years, countries that have been able to produce flexibly and at low cost, utilizing a low-cost labor force compared to other countries, have become highly competitive in the global value chain. According to the BCG Global production cost index, which is based on wages, productivity, energy costs, and exchange rates, developed countries such as Canada (115), the United Kingdom (109), Germany (121), France (124), and Italy (123) produce at an average unit cost, while developing countries such as China (96), Turkey (98), Taiwan (97), Thailand 91, India 87, and Indonesia 83. In other words, production costs in developing countries are on average 20% lower than in developed countries. This situation has so far created a disadvantage for developed countries seeking to increase their competitive strength. Advanced countries that rapidly implement Industry 4.0 will regain their cost advantage, leading to a shift in the global competitive balance in their favor. If, as expected, Industry 4.0 results in a 20% reduction in production costs, the competitive advantage enjoyed by developing countries will almost entirely disappear (Tüsiad, 2016: 33-36). This outcome will cause the gap between developed and developing countries to widen once again.

In the early stages of the transition to Industry 4.0, a new inequality will emerge between countries that adapt more quickly to and utilize the elements brought about by Industry 4.0 and those that are not yet able to utilize them sufficiently (or at all). For this reason, the law of unequal and compound development will need to be reconsidered.

Table 2: Industrial Product Sales (Billion $).

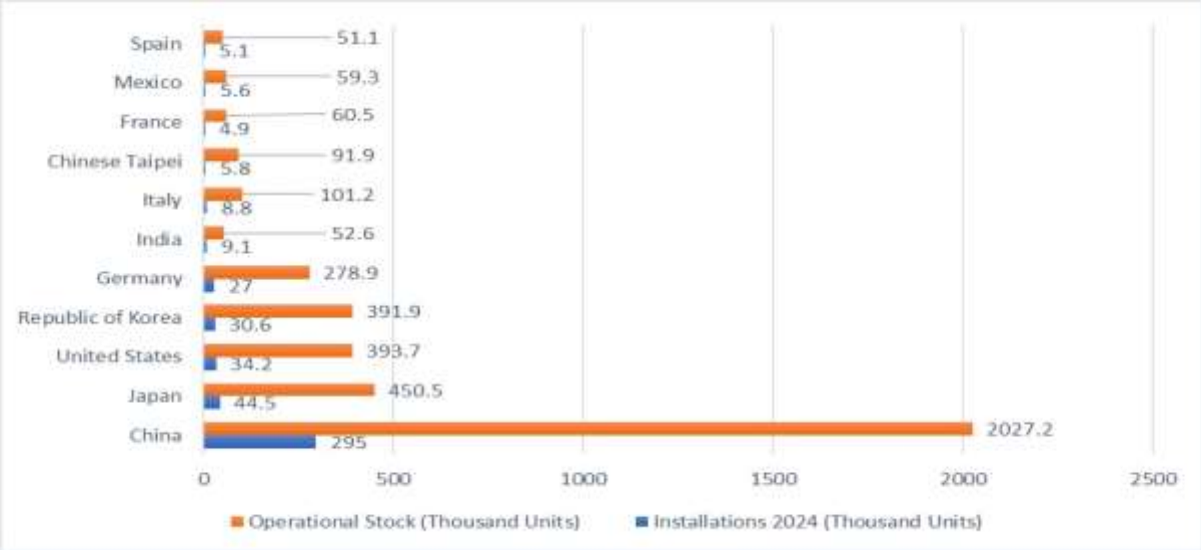
Country	2006	2011	Change (%)
Eurozone	550	620	13
USA	280	280	0
Germany	190	220	16
Russia	10	15	50
China	170	580	241

Source: Kagermann et al., 2013

Table 2 clearly explains one of the underlying reasons for Industry 4.0, particularly for developed countries. Table 2 shows the revenues countries earned from industrial goods production before the Industry 4.0 process began, comparing the years 2006-2011. China, in particular, has seen a significant increase in industrial goods production thanks to the direct foreign investment it has attracted, partly due to its cheap labor. In contrast, the level of increase has remained low in the United States and Eurozone countries. In this context, it is expected that the successful implementation of Industry 4.0 will eliminate the competitive advantage that China and similar countries have gained due to cheap labor.

However, it is debatable what the situation will be if countries that use cheap labor also adopt Industry 4.0 rapidly (Aksoy, 2017: 43).

Figure 2: Annual Industrial Robot Installation (Thousand Units).



Source: IFR 2025 (International Federation of Robotics).

Looking at the number of new industrial robots put into production by countries in 2024, it is seen that a large portion of them are manufactured by developed countries. China, Japan, the US, Korea, and Germany lead the way in annual new robot installations. A similar situation is observed when looking at the total number of robots used in production. China has a large share of the total number of robots worldwide. Many developing and underdeveloped countries, however, do not appear on this list. If the number of robots continues to increase at the same rate in the coming years, the use of robots in production in developed countries will become increasingly widespread, leading to cost advantages and increased efficiency. As a result, the income gap between developed countries and developing and underdeveloped countries will widen further. Countries such as China, India, and Mexico, where wages are low, are focusing on automation rather than just taking advantage of cheap labor. This can be interpreted as their desire not to lose the competitive edge they gained in the previous industrial revolution. The fact that developed countries are placing a high priority on robotization supports the argument that they want to regain the competitive edge they have lost by utilizing Industry 4.0.

3. MACROECONOMIC CHANNELS OF DIGITAL TRANSFORMATION

Every industrial revolution has had serious consequences for economic life. In particular, the increases in production that emerged with industrial revolutions have led to changes in many economic factors such as the growth of countries, employment levels, foreign trade, capital accumulation, and the distribution of investments. Furthermore, they have produced different outcomes for developed, developing, and underdeveloped countries. As Industry 4.0 is increasingly adopted by countries and companies operating within them, numerous macroeconomic factors will be affected by this development. Some of these effects will manifest in the short term, while others will become apparent in the medium and long term.

3.1. Technological Advancement and Economic Growth Dynamics

The positive effects that Industry 4.0 is expected to have on production include reduced production costs, increased efficiency, energy savings, accelerated production processes through the use of robots, shorter time-to-market for new products, more effective use of scarce resources, and optimal capacity planning. As a result of these changes, economic growth dynamics will also change (TOBB, 2016: 16-27). The adoption of Industry 4.0 will facilitate high value-added production opportunities. Increases in the production of value-added products will contribute to qualitative sustainable growth. Thus, the new production style will have a positive impact on economic prosperity through resource efficiency and cost reductions. (European Commission, 2013: 111). The annual economic impact of industrial robots is expected to be between $0.6 and $1.2 trillion by 2025. By 2030, digital technologies are projected to have a powerful impact on productivity, income distribution, and the environment, with approximately half of global trade volume expected to be conducted through the interaction of smart objects (Tübitak, 2016: 2).

Digitalization and the Industry 4.0 revolution are driving growth across all sectors through the transition to automation. The adoption of robotic approaches to optimize production processes and robots with advanced functionality are boosting growth (Dhapte 2024). In this context, the transition to Industry 4.0 offers various opportunities for growth. Companies need to make new investments to adapt to the new technologies required by Industry 4.0. These investments include new machinery, equipment, robots, and other production goods. This will support growth both economically and industrially on a global scale. In other words, both the increase in investment spending and the resulting increase in production will have a positive impact on growth. Furthermore, the positive effects of Industry 4.0 on companies' costs are also expected to have a positive impact on growth. These effects will contribute to the growth of the global economy.

In the future, Industry 4.0 and the growth process can be expected to progress in a mutually reinforcing spiral. The digitalization and robotization brought about by Industry 4.0 and Society 5.0, among other factors, demonstrate a quality that supports growth (quantitative increase in production). As a result of all this, the increase in profits achieved through increased production will push companies to embrace Industry 4.0 more and invest in further robotization.

3.2. Digitalization, Income Distribution, and Inequality Mechanisms

Industrial revolutions and globalization have led to the accumulation of capital in certain hands; the accumulation of capital in certain hands has led to increased income inequality in countries. This situation has caused a divergence rather than a convergence in income levels worldwide. There are issues of equality in the distribution of gains among regions, states, and individuals around the world. These inequalities in income distribution create the conditions for various potential conflicts (Intriligator, 2003: 9-10).

Eleanor Roosewelt Institute (2015: 3) argues that the application of new technologies to production has reduced the number of jobs available to the middle class. On the one hand, low-skilled and low-wage jobs are increasing, while on the other hand, very high-wage, high-level jobs are also increasing. This situation is creating increasing polarization in the labor market. Supporting this argument, another study conducted by the Pew Research Center (2015) in the United States found that the incomes of middle-income groups have declined over the past forty years. Of course, this situation cannot be attributed solely to developments in information technology. However, the long-term parallelism is noteworthy (Degryse, 2016: 42). In the final years of Industry 3.0, developed countries experienced declines in industrial production, and the middle class, whose main source of income was long-term, high-paying jobs in industry, shrank significantly. Furthermore, countries such as the United States, Germany, France, and the United Kingdom have seen serious declines in the proportion of people employed in the industrial sector over the past 40 years (Baransel, 2017: 20).

The transition to a new phase with Industry 4.0 will increase efficiency in the short term. However, this situation will not benefit everyone in the short and medium term. Unskilled workers, who are unnecessary as producers but beneficial as consumers, will continue to bear the burden of change. If no action is taken, economic inequality will continue to increase and cause various problems (Brynjolfsson, 2014: 52)

In Industry 4.0, the need for a skilled workforce that can effectively utilize information technologies will increase, which may further widen the wage gap between skilled and unskilled labor. In particular, the fact that many of the jobs performed by unskilled workers will begin to be done by robots may increase unemployment in the short term by causing structural or technological unemployment in some sectors. As a result of this segment becoming unemployed, the imbalance in income distribution will increase further. Industry 4.0 will increase the number of skilled workers. However, not everyone in the world has access to the same level of education. According to poverty theories, there is a close relationship between education level and poverty. Consequently, the income gap between the poor, who do not receive adequate education, and the educated, high-income segment may widen further.

3.3. Transformation of Capital and Labor Shares from a Factor Income Perspective

Marx defined the organic composition of capital simply as the ratio of fixed capital to variable capital.

$b = c / v$ (1) It is calculated using the equation formulated as follows. The organic composition of capital also indicates the degree of mechanization of the producer in the capitalist system (Widodo, 2008).

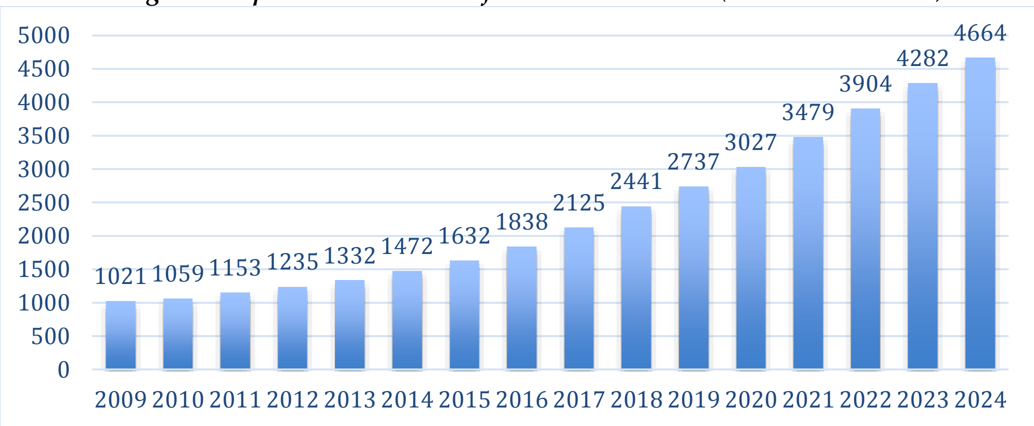
Marx concluded that the organic composition of capital would increase as the share of machinery—the fixed component of capital—in production increased more than the use of labor power, the variable component of capital. The replacement of labor with new technologies in production reduces the demand for labor. On the other hand, technological advancements in production can create significant productivity increases for capital, but can also have negative consequences for labor (Aksoy, 2017: 38). If, as a result of the robotization process in Industry 4.0, capital increasingly replaces labor, the gap between the return on capital and the return on labor may widen even further. However, in this new era driven by digital technologies, the most valuable resource will not be ordinary labor or ordinary capital, but people who can create new ideas and innovations. In the future, talent will represent a more critical factor in production than capital (Brynjolfsson, 2014: 46). One of the consequences of industrial revolutions has been that the capital factor in production has grown faster than the labor factor. Robots and dark factories, which will emerge with Industry 4.0, will lead to a further widening of this gap. With Industry 4.0, this ratio will shift even faster in favor of capital. In this respect, Industry 4.0 has the potential to increase the inequality between labor and capital.

3.4. Structural Change in Labor Markets and its Employment Effects

The impact of the transition to Industry 4.0 on the labor market is a highly debated topic. Digital technologies and robotization, which are fundamental to Industry 4.0, are the most discussed aspects of this. Those who oppose the view that Industry 4.0 will increase unemployment emphasize that technological advancements always create new job opportunities and argue that Industry 4.0 will create more jobs than it causes.

Figure 3 shows the number of robots used in production in businesses worldwide. It can be seen that the number of industrial robots in businesses has increased more than fourfold between 2009 and 2024. It is understood that these figures will reach much higher levels in the coming years as Industry 4.0 becomes more widespread. This situation is expected to have a negative impact on employment, particularly in some areas, as robots may replace unskilled labor.

Figure 3: Operational Stocks of Industrial Robots (World 1000 Units).



Source: Gemma et al, 2017:15 and World Robotics 2025

Table 3 provides clues about how the employment market will shape up in the future. According to this, as automation and digitalization in production increase, some occupational groups in manufacturing, construction, and logistics face higher risks. In contrast, those working in fields such as education, arts, law, and information technology face less risk. Furthermore, new job areas have emerged with each industrial revolution. With Industry 4.0, new job areas such as robot manufacturing and maintenance, artificial intelligence, data analysis, systems analyst, and software engineering can be expected to emerge.

Ultimately, structural transformation will lead to the disappearance of some job areas while also creating new ones. Table 3 shows which work areas may pose greater risks due to automation and robotization, and which areas may create new jobs.

Table 3: Jobs in the Digital Economy.

Jobs Most at Risk Due to Automation and Digitalization	Jobs with the Least Risk Through Automation and Digitalization	New Jobs
• Office and administrative work • Sales and trade • Transportation and logistics • Manufacturing industry • Construction • Some financial service sectors • Some types of services (translation, tax consulting, etc.)	• Education, art, media • Legal Services • Human Resources Management • Some financial service sectors • Health services • Computer industry, engineers, scientists • Some types of services (social services, hairdressing, beauty care)	• Data analysts, data miners, data architects • Software and application developers • Network experts, artificial intelligence, etc. • New smart machine, robot designers, and manufacturers • Digital marketing and e-commerce specialists

Source: Degryse, 2016:23

Industry 4.0 and its accompanying elements will create unprecedented levels of automation in routine tasks. Digitalization, networked systems, the Internet of Things, and many innovations brought about by Industry 4.0 will eliminate some of the tasks currently performed by employees. If employees do not want to be left out of this revolution in the future, they must improve their skills. These skills fundamentally encompass improvements in attitudes and ethical values, as well as advancements in learning and cognitive abilities. (Angolla, 2018: 44). Another effect of robots on the employment market is that the use of robots in jobs that threaten human health will eliminate occupational safety risks (Alkan, 2016).

Artificial intelligence can be defined as the effort of a computer or computer-assisted machine to perform logical processes that are among the basic qualities of humans, such as understanding, interpreting, generating problems, generalizing, and learning from past experiences (Nabiyev, 2016: 25). The developments related to artificial intelligence, which has become an increasingly popular concept recently, accompanying Industry 4.0, will create a threatening situation for some professional groups.

In sectors that are becoming robotized with Industry 4.0 and further digitized with artificial intelligence, the replacement of labor with robots is creating a negative outcome for the workforce. The widespread use of artificial intelligence in various sectors is leading to the workforce lacking technological literacy being increasingly excluded from employment. This transformation process, combined with the limited education level, skills, and technological knowledge of the current workforce, causes this segment to be more negatively affected by the process. Furthermore, artificial intelligence has an effect that makes it difficult for unskilled workers to re-enter the workforce (Misican, 2021: 153). Although there may be a decline in the number of workers, Industry 4.0 will still require a skilled workforce with planning capabilities and programming knowledge (Aksoy, 2017: 38).

Industrial robots are mechanical devices to perform certain stages in the process of producing goods and services. Industrial robots create significant flexibility in production due to their reprogramming capabilities, ability to work without time constraints, and versatility. While these features will cause the industrial robot market to grow rapidly in the future, factors such as high initial costs and technical complexity limit market growth. Today, robots are used in many fields (healthcare, agriculture, retail, logistics, defense, construction, maritime, education, entertainment, etc.) alongside industry. Their increasing use, particularly in areas where unskilled labor is employed, will have a negative impact on the employment market.

Figure 4: Annual Amount of Industrial Robots Installed in the World (Thousand Units).

Source: World Robotics 2025:23 *Forecast.

Figure 4 shows the number of new robots added each year to the existing number of industrial robots worldwide. There is an upward trend in the number of newly installed robots each year. The number is expected to increase further in the coming years. This situation can be interpreted as countries that do not want to fall behind in global competition wanting to integrate technology into production more. However, these robots replacing the workforce will lead to increased unemployment. On the other hand, countries that fail to adapt to Industry 4.0 may experience a decline in their competitive strength, a decrease in market share, a drop in production, and again, increased unemployment. Therefore, adapting robots to production will increase production, competitiveness, market share, and the ability to produce more value-added products, which will bring about production growth and expansion, thereby creating employment in other areas.

Each industrial revolution has generated similar concerns about unemployment due to the increased mechanization of production. Industry 1.0 raised concerns about the first-ever use of machines in production; Industry 2.0 concerned the need for fewer workers due to the Fordist production method; Industry 3.0 worried about the use of computers in production; and Industry 4.0 feared that robots would replace labor. Society 5.0, however, somewhat alleviates these concerns by portraying robots as being for humans or reflecting human-robot collaboration in production. With Society 5.0, the ability to produce goods according to consumer demands will come to the forefront.

In light of all this, it is not easy to draw a clear conclusion about the effects of Industry 4.0 on the labor market. It would be more accurate to look at the effects Industry 4.0 will have on the labor market in the short, medium, and long term. Robotization will cause an increase in unemployment, referred to as “technological unemployment,” and structural unemployment in the short term, while some old professions will lose their popularity, some professions will disappear due to structural transformation, and some new occupational groups that did not exist before will emerge. Unemployment will increase, particularly in certain fields that rely on physical strength. In the medium and long term, however, this will lead to an improvement in the quality of the workforce. This is because there will be a growing need for skilled personnel who are experts in information technology, capable of quickly analyzing data and transferring it to the production process, managing robots, and possessing the qualities required for Society 5.0. It will be easier for employees who can improve their skills, experience, education, and knowledge level, which are required by Society 5.0, to find jobs. The situation of current employees will be determined by their ability to use information technologies well and develop their knowledge and skills through new training. In addition, thanks to Industry 4.0, many new products can be developed, and new sectors that did not previously exist may emerge. The new personnel needs of these sectors may contribute to increased employment.

The concept of mass automation brought about by Industry 4.0 is evolving towards the personalization of products and the further development of human skills with Society 5.0. Questions that need to be answered in the future include: what skills are necessary and need to be developed, how will the interaction between humans and machines be, and what kind of impact can artificial intelligence have (Paschek et al., 2019)? How the structure of the labor market will change will depend on the answers to these questions.

4. LABOR MARKET AND HUMAN CAPITAL-FOCUSED TRANSFORMATION PROCESSES

The themes under this heading will effectively link the Society 5.0 vision for a human-centered approach to the macroeconomic plane. In this framework, some key discussions will address the struggle of human beings to gain a share in this struggle, as production mechanisms are increasingly oriented towards more efficient, higher production, and lower costs within a capitalist understanding.

Over the last 25 years, China's use of cheap labor to dominate the low-cost product market has heightened the challenges faced by countries competing globally. This fierce competition has put companies in developed markets, such as those of the OECD, in a survival battle, driven by the mantra 'if you don't innovate, you die.' Continuous innovation, technological upgrades, and evolving production and trade strategies in a competitive environment drive efficiency gain, which transform the labor market. Despite the growing complexity of macroeconomic factors, the ongoing interaction and mutual reinforcement between trade and technology remain persistent (Van Reenen, 2011).

It is noted that the impact of emerging artificial intelligence and other Industry 4.0 technologies on labor markets has created two opposing camps. One is the belief that workers displaced by technology will get new jobs and that technology will bring about in a new era of prosperity; The other is the belief that mass technological unemployment, which is called structural unemployment, will cause a social and political disaster (Schwab, 2017). One of the most popular proponents of the second viewpoint is, without a doubt, Y. N. Harari. In his popular book Homo Deus, he argues that while scientific and technological advancements will create an elite class of people, a "useless class" will also emerge, composed of individuals who play no role in economic, political, or artistic production and cannot contribute to society, potentially forming an army of unemployed people who cannot be hired (Harari, 2017).

Studies on the impact of artificial intelligence on employment, at least for now, are far from supporting Harari's (and others') radically questioning perspective. A firm-based study by Hampole et al. (2025) covering the period 2014-2023 found an artificial intelligence-induced labor-substitution effect. However, the study revealed that this effect is weakened by counteracting effects, such as intra-firm labor reallocation and increased firm employment.

4.1. Employment and Skill Polarization: AI Digital Transformation and Its Impact on the Labor Market

In relation to the qualified technological change hypothesis, Lee & Wie (2015) analyzed its effects on the Indonesian manufacturing sector using regression analysis of data from the National Labor Force Survey for the years 1990-2009. According to the analysis, as technology penetrates workplaces, the demand for educated and skilled workers increases. As foreign technologies spread, labor demand shifts toward more highly skilled workers. Another reason is that technology transfer through imported technical products increases the demand for skilled labor.

According to the UN (2020), two different criteria were used to assess polarization. The employment share criterion, which defines 'the percentage of jobs at a certain skill level within total employment,' aims to understand whether the share of such jobs within employment is decreasing or increasing. The job count criterion considers the absolute number of jobs based on ILO data from 113 countries, which represent approximately 58% of the world population. Regarding polarization, especially in medium-skilled jobs, the findings of this study indicate that, over time, the proportion of these jobs within total employment has decreased in about 76% of countries. On the other hand, a striking observation concerns the absolute situation: in approximately 76% of these countries, there has been no decrease in the absolute number of such jobs. Therefore, even if the share of medium-skilled jobs in employment has decreased, the absolute number of medium-skilled jobs has stagnated or increased. For high-skilled jobs, at least 80% of the countries show an increase in their share, with over 90% experiencing growth in absolute numbers. Although more than 56% of countries with low-skilled jobs appear to have a decreased share, in 69% of these countries, the absolute number of such jobs has increased.

Table 4: Change in composition of labour force by skill level (1990s to 2010s).

Direction change	Share of jobs			Number of jobs		
	Low-skill	Middle-skill	High-skill	Low-skill	Middle-skill	High-skill
Increase	44%	24%	81%	69%	76%	92%
Decrease	56%	76%	19%	31%	24%	8%

Source: ILOSTAT (2020).

According to the Future of Jobs Survey 2025 published by the World Economic Forum, between 2025 and 2030, due to structural labor market transformations, a net of 7% of total employment (78 million jobs) is expected to emerge, comprising 14% job creation (170 million jobs) and 8% job loss (92 million jobs). Employers surveyed indicate that advancements in three of the nine key technologies in particular will transform their businesses. 41% cited energy generation and storage technologies, 58% mentioned robots and autonomous systems, while this figure rose to 86% for artificial intelligence and information technologies. Similarly, big data expertise, fintech expertise, AI and machine learning expertise, and software and application development ranked highest as the four professions expected to grow the fastest (World Economic Forum, 2025).

Some studies in this field suggest that developments in information technology will not produce a homogeneous and uniform effect on labor markets. Frey & Osborne (2017), using a method to estimate the probability of digitalization for 702 occupations in the US, classified this probability as low, medium, and high. According to their calculations, 47% of jobs in the US were in the high-risk group. They predicted a truncation in polarization, with the trend of computerization in the labor market remaining limited to low-skilled, low-wage jobs. Based on this finding, they predicted that computerization would primarily affect low-skilled, low-wage jobs. However, Hampoli et al. (2025) stated that high-paying jobs and professions would be more heavily affected by artificial intelligence. As can be seen, the speed, dynamism, and direction of technological development rapidly update predictions and findings as well.

4.2. Human Capital Investments and the Technological Unemployment Paradox from the Perspective of Society 5.0

This section examines the connection between the human-centered transformation, defined as Society 5.0, and the macro-level problem of unemployment.

The expansion and polarization of technology-based models in the labor market have provided an explanation for change. Developments in ICT (Information and Communication Technologies) involve the use of computers for various tasks, with routine operations increasingly being taken over by machines. ICT has complemented highly skilled workers performing non-routine analytical tasks. It has also replaced moderately skilled workers performing routine tasks, such as office work. It has been noted that low-skilled, non-routine manual jobs (cleaning, waitressing, etc.) have not been significantly affected by ICT developments at higher levels. Growth is observed in both high-wage and low-wage jobs through this task-oriented technical change model. The concentration and polarization of the market at both the lower and upper levels, observed with a decrease in nonexistent jobs, are noteworthy. These potential technological developments have had varying degrees of impact on markets at different times (Van Reenen, 2011).

The use of automation and artificial intelligence technologies is expected to transform the workplace and the employee due to increased human interaction with intelligent machines. These technologies will accelerate skill shifts for individual employees, from basic cognitive skills to technological expertise, social interaction, and higher-level mental abilities. This transformation will also have profound effects on how companies organize themselves. Companies will need to redesign their work approaches and corporate organizations in order to take advantage of these opportunities. This redesign process can be seen as focusing on existing and expected capabilities. It is emphasized that, to adapt to this transformation, companies need to embrace a culture of lifelong learning, make their business processes more agile, and retrain their employees. (McKinsey Global Institute.2018).

Data collected from a significant number of employees and companies in Denmark between 1999 and 2009 indicates that the competitive environment surrounding imports has led to adjustments at the employee level. It is noted that the impact of this shock was most pronounced among employees performing manual tasks, regardless of whether they were in routine or non-routine work. While trade forces domestic workers into competitive conditions, technological advancements are creating a race between humans and machines for roles in production. Trade-related shocks impact employment, creating a U-shaped employment pattern. Competition related to imports leads to a significant decrease in employment years for workers in middle-wage occupations (machine operators, crafts). These shocks cause a decrease in employment at both the high-wage (management-related, professional) and low-wage (services sector, unskilled) extremes of the employment distribution (Keller and Utar, 2016)

4.3. Wage Shares, Wage Inequalities, and Income Distribution in the Digital Transformation Process

From the late 1980s to the present, complex changes have been observed in income distribution. Studies focused on U.S. data highlight a heterogeneous transformation in income distribution. Related to the concept of polarization, faster income growth at the lowest and highest income levels has led to slower growth at middle-income levels. Notably, findings for the United States and the United Kingdom show particularly striking disparities between inequality at the upper tail and the lower tail of the distribution. The author also notes that wage developments have played a role in the evolution of professions, with higher growth in low- and high-wage occupations and a decline in middle-wage occupations, strengthening evidence of job polarization. Similar developments in other advanced OECD countries have also been associated with the polarization model, indicating a widespread trend among industrialized nations (Van Reenen, 2011).

The Occupational Risks Posed by Automation for Routine Tasks: The authors note that technological change does not have equal effects on workers' social lives and that it produces different outcomes depending on Routine Task Intensity (RTI). Workers in occupations with high RTI scores are at high risk of job and wage loss as robots increasingly dominate future job transformations. This is because, compared to the processor or computer logic running in the background of robot logic, well-designed software can easily replace defined and repetitive routine tasks with well-defined rules (Thewissen and Rueda, 2019).

Technological advances increase demand for skilled workers while decreasing demand for unskilled workers. As a result, skilled workers may receive higher skill premiums, which can widen wage inequality. Researchers, using Indonesia as an example, have noted a trend in nearly 30 years of manufacturing sector data showing that, despite rapid growth and a decrease in inequality after 1990, the decline reversed around 2003. They emphasized that after this period, wage inequality indices began to rise again, and that technological changes were among the contributing factors (Lee & Wie, 2015).

In addition to being a source of wage differentiation among employees, the transformation process can also have different effects on functional income distribution, which expresses the distribution of income among factors of production, or on personal income distribution, which includes households. New technologies can increase labor demand due to higher productivity (lower production costs), sectoral growth, or increased demand for complementary work in production. This increase in productivity can lower the prices of goods and services, enriching households. This real increase in income can boost demand for all goods and services in the economy, creating positive effects on welfare. However, the displacement phenomenon can also lead to a decrease in the share of output received by labor by reducing the share and contribution of labor in production (or by increasing capital intensity), causing productivity to increase faster than labor wages (Acemoğlu & Restrepo (2020). Essentially, the probabilistic context surrounding the emergence of these developments is rooted in the uncertainty surrounding the developmental path of the new technological transformation, including artificial intelligence, as it is still in its developmental stages.

4.4. Taxation of "Smart Social Security" and Automation in the Society 5.0 Vision

Under this heading, we have focused on unique themes with views that can also serve as policy recommendations and enable the imposition of Society 5.0 on the production system. For this purpose, the “Robot Tax”, “Smart Social Security” and the macroeconomic sustainability of the Universal Basic Income (UBI) model will be discussed as examples of solutions to prevent the blockage of the economic system.

The “Smart Social Security” approach emphasizes Society 5.0 as a way out for the gradual failure of the human leg of humankind. From a public finance perspective, there are efforts to develop solutions on how technology can create financial resources not only for production but also for the aging population and social welfare.

Traditional income models such as the Meltzer-Richard Model focus on current income, but in the related study, two different arguments were mentioned to draw attention to insurance motivations. Insurance Motivation Argument: Workers in occupations with high RTY scores work with an increased risk of being laid off due to automation. They support income redistribution as a form of self-insurance and risk insurance. The Mediating Role of Income: Contrary to the approach that the wealthy always oppose income inequality, the authors argue that the effect is greater or stronger in the wealthy with high RTY scores. This is because high-income workers are more likely to suffer harm from occupational hazards than low-income workers

(Thewissen and Rueda, 2019).

The rapid pace of AI-based technological innovation has presented humanity with numerous opportunities but also exposed it to significant societal risks. Public administrations are working intensively to enact legislation to regulate developments in AI. However, doubts and cautious approaches regarding the technical and non-technical trust aspects of AI infrastructure, along with the seriousness of the risks associated with the adoption of AI in society, have prevented the rapid integration of AI developments into societies without fully foreseeing the full extent of these risks. In relation to the concepts of corporate and AI trust, it is crucial to inform the public about the risks associated with certain parts of the AI ecosystem, and to provide governance support to enable firms or professional institutions to integrate into new developments through strong regulatory policies or to steer clear of certain aspects (Bullock, 2025).

The view that robots, which are the devices where artificial intelligence is used most intensively, will take away people's jobs is widely discussed, and some proposals are being put forward to address this. The most concrete of these views is Universal Basic Income (UBI), and a robot tax as a method for generating it. Technological unemployment, a form of structural unemployment that arises from robots taking over jobs, has the potential to plunge societies and individuals into destitution. To prevent this situation from arising or to mitigate its consequences, taxing robots is proposed as a source of financing to guarantee an UBI for people (Kireçtepe, 2022). UBI is a model that envisages the regular, cash, personal, universal, and unconditional provision of a fixed amount of money to all citizens of a country or other geographical region, regardless of their income level, resources, or employment status. The main aim of UBI is to prevent or reduce poverty and to increase equality among people (Miller, 2019).

The displacement of workers by robots will affect not only workers' incomes but also public revenues. This digital exclusion of labor will increase the need for public revenue, both by reducing tax revenues, including social security income, and by increasing public spending through training programs and social transfers to help the unemployed adapt to technological change. To compensate for the decrease in public revenues and the increase in public expenditures, robots can be taxed in several ways: by taxing based on the income employees would have earned if they had done that job; by imposing a progressive automation tax based on the number of employees they displace; If workers were doing this job instead of a robot, by taxing equal to the collected social security contributions; by subjecting their activities to value-added tax; by imposing fees for their use of public services in their operations; by raising the corporate tax rate to increase the tax on capital; and by raising the value-added tax on the purchase of robots to a reasonable level. Slowing down labor substitution by reducing or eliminating the tax rate on workers' wages is also suggested (Ela, 2019).

4.5. Creative Destruction Adapted to Artificial Intelligence and Labor's Revolt Against Capital

J. Schumpeter's concept of “creative destruction”, developed in his book “Capitalism, Socialism and Democracy”, describes the working principles of the capitalist system as a process of continuous elimination of old production structures and market positions by innovative initiatives. According to Schumpeter (1942), capitalism is a non-stationary, structurally revolutionary system in which the capitalist structure, fueled by technological innovation and entrepreneurial motivation, transforms the existing economic order from within. On the other hand, K. Marx, in “Capital” and “The Accumulation of Capital”, explained the existence of a structure suitable for producing crises due to the internal contradictions of the capitalist mode of production, and argued that the proletariat would eventually become the new subject of the economic system with a revolutionary quality and cause the system to be reconstituted (Widodo, 2008). Both approaches treat capitalism not as a static but as a historical system shaped by internal tensions and dynamics of transformation. However, while in Schumpeter the transformation process proceeds through an innovative competition within the system, in Marx it is predicted that the transformation will be fueled by class conflicts and a revolutionary destruction of the system due to the structural contradictions underlying the relations of production. In this respect, creative destruction and the prediction of proletarian revolution, although they are two different constructs regarding the unstable and transformative nature of capitalism, offer theoretical explanations that intersect analytically.

Predictions about the overlap between these theoretical frameworks and the concept of artificial intelligence are being made, even though the artificial intelligence transformation is still in its infancy. Different predictions have begun to be developed on the dominance of artificial neural networks, machine learning, deep learning and productive artificial intelligence software innovations that enable automation processes to be increasingly equipped with algorithms that imitate the human mind. The fact that the machine has qualities that can compete with and imitate human beings, while leaving behind the mechanical and human-dependent working mechanism, raises the possibility of the validity of the theories mentioned above. Because with the transformation of artificial intelligence, developments that overlap with the concept of creative destruction lead to the prioritization of machines equipped with artificial intelligence and the exclusion of old technology automatic systems. This transformation process may allow human beings to adapt to the new system, as in previous revolutions.

The predictions related to Marx's approaches, on the other hand, put forward important grounds for the system's exclusion of human beings as artificial intelligence becomes increasingly capable. Because as artificial intelligence gradually substitutes the labor factor in the production system and shifts the share of production in favor of the machine, there will be a possibility that the capitalist production levels will be enriched, while on the other hand, the labor factor, which cannot compete with the machine, will not get enough share of the production share. In this case, if it is assumed that the production system will feed itself through demand, it may trigger a revolutionary process similar to that envisaged by Marx if the labor factor cannot secure an adequate share of production and feed the system. To prevent such situations, decision-makers in the economic administration may propose solutions, such as subsidies that do not erode the purchasing power of the labor factor or threaten the capitalist sector.

4.6. Discussion

In line with technological developments, production systems have also evolved, playing a decisive role in the emergence of industrial revolutions by transforming society across different spheres of influence. In this context, the international public was informed through official reports that the Industry 3.0 phase, which covers digitalization and automation-based production systems, was completed in 2011 and that the Industry 4.0 process, as a new paradigm in industry, had begun. This transformation process represents not only a technological renewal for individuals, companies, societies and countries, but also a strategic breaking point where competitiveness and trade rules are redefined.

In this context, predicting the economic and structural consequences of Industry 4.0 and effectively leveraging its opportunities are critical for national economies and businesses. The main factors influencing the emergence of Industry 4.0 include the quest to further increase productivity in production processes, the efforts of developed economies to regain the competitive advantage they have lost globally, and the advantages provided by flexible production structures enabled by the spread of robotics.

Although new concepts such as robotization, internet of things, etc. have entered the literature with Industry 4.0, individuals will constitute the main driving force of the economy in the future as in the past within the framework of the Society 5.0 approach. With the stages of industrialization, labor based on brain power has replaced labor based on muscle power. In this process, economies that can effectively adapt technological changes to their economic structures and industries, and invest in individuals, have come to the fore. This situation will continue with the perspective of Society 5.0 after Industry 4.0.

However, the uncertainty and controversy surrounding this expectation is closely linked to rapid developments in the field of artificial intelligence. As production systems are increasingly structured around AI-based management and decision-making mechanisms, the central role of the individual in the production process is weakened, and the possibility of decision-making processes being transferred to machine learning-based systems through automation is strengthened. This situation necessitates a reassessment of the relationship between Society 5.0's human-centered approach and AI-focused production systems.

When evaluated over a short projection period, the Industry 4.0 process has the potential to further deepen the economic gap between developing and developed countries. The expected increase in production associated with Industry 4.0 favors developed countries that have the capacity to produce high-value-added products; meanwhile, for less developed countries, where physical, human, and technological capital required for this transformation is relatively scarce, there are significant short-term disadvantages. In the medium and long term, the speed at which countries that currently gain a competitive edge through relatively low labor costs adapt to Industry 4.0 will become a key factor in determining their position within global value chains. If developing countries with large populations fall behind in high-value-added, technology-intensive production, the increased domestic demand will largely have to be met through imports, further widening the economic gap with developed countries. In this context, it appears inevitable that less developed countries, which rely solely on labor factors, maintain low-value-added production and import technology-intensive products, will be adversely affected by Industry 4.0.

One of the fundamental outcomes of industrial revolutions is rapid, continuous increases in production capacity. However, for this increase in production to translate into sustainable economic growth, it is also necessary for the goods and services produced to be effectively directed toward consumption. In this context, with Industry 4.0, increases in productivity, reductions in costs, and expansion of product diversity are laying the groundwork for higher trade volumes at the country and global levels by positively supporting domestic and foreign demand. In particular, the development of smart production systems and digitalization is making global value chains more integrated. This integration into global value chains, which offers countries the opportunity to make a leap forward in their development, is among the key factors that strengthen the impact of Industry 4.0 on international trade.

When evaluated in terms of income distribution and wage structure, the Industry 4.0 process is expected to have a disruptive effect on income distribution by increasing the gap between high and low-income groups. For high-income groups who own capital, the integration of robot technologies into production processes will lead to a decrease in costs and, in parallel, increases in production and productivity will boost their incomes. In contrast, some workers in the low-income group, generally defined as unskilled labor, will face the risk of losing their jobs or experiencing a decline in wages as a result of being replaced by robots in these areas with Industry 4.0. This situation will increase the economic pressure on low-income groups. On the other hand, with artificial intelligence technologies taking on a dominant role in industrial and service production, the possibility of economic pressures on white-collar workers and upper-middle-income groups has gained strength.

The effects of the skilled-unskilled labor force divide are expected to increase demand for skilled labor with knowledge and skills in software, information technology, and production processes. While wages for employees in these fields are projected to rise, a more pronounced skill-based divide in the labor market is anticipated. These developments are among the factors that could contribute to deepening income inequality in the Industry 4.0 process. However, with artificial intelligence playing an active role in production processes, it may be possible for tasks previously performed by skilled labor to be carried out by a small number of white-collar workers in the future. Along with these developments, the phenomenon whereby skilled labor became integrated with elite status and higher income levels in the post–Industry 3.0 period has faced the possibility of a reversal in the post–Industry 4.0 process.

With Industry 4.0, the share of the capital factor in the production process is expected to increase faster than the labor factor. Replacing labor with robots, especially in areas that do not require qualifications, will have negative effects on the labor market in the short term while increasing the share of capital in production. However, it is also an accepted fact that historically, each industrial stage has led to production becoming more technological and the share of the labor factor in the production process gradually decreasing. With the inclusion of AI-based production processes in the production system, the efficiency and returns of the capital factor may increase, leading to an increase in the share of income. Since algorithms, autonomous systems and data infrastructures require high fixed investments, firms that have these technologies can largely transform economies of scale and productivity gains in favor of capital. The marginal productivity of the labor factor decreases, especially in routine and automated jobs, and this puts downward pressure on the share of labor as the marginal productivity of capital increases. However, in areas requiring advanced skills that are complementary to artificial intelligence, the productivity and bargaining power of skilled labor is expected to increase, and in addition, a quality-based decomposition in the labor share is expected to emerge.

The likely impacts of Industry 4.0 on the labor market differ in the short, medium and long term. In the short term, it is expected that there will be less need for unskilled labor with the widespread use of robots in production and the introduction of applications such as dark factories. This will have negative effects on the labor market due to technological substitution and structural unemployment that may increase during the structural transformation process. In addition, the emergence of adjustment costs in the short term may make it difficult to reemploy workers, especially those with low skill levels. Failure to use training and reskilling mechanisms effectively may increase the risk of technological unemployment becoming permanent rather than temporary. Moreover, if firms prioritize and focus on automation investments with an efficiency-oriented approach, employment growth may be more limited compared to production growth. Another risk is that AI-based systems may partially take over white-collar labor-specific tasks such as decision-making, planning and supervision, which may lead to the substitution of unskilled labor tasks as well as some routine medium-skill jobs. In the short term, this may increase uncertainty in the labor market, making employment transitions more difficult. Failure to provide digital and analytical skills in the labor factor to adapt to artificial intelligence may have a negative impact on the relevant factor.

Within the framework of Medium and Long-Term Employment Dynamics, it was expected that the increased technological integration of production in the Industry 4.0 phase, compared to previous industrial phases, would pave the way for the emergence of new job areas and an increase in employment in the medium and long term. Historically, the total number of employees has increased in parallel with economic growth driven by the industrial revolutions. In this context, significant reductions in costs were expected across production, logistics, quality, and maintenance with Industry 4.0. It was predicted that these cost reductions would have a positive impact on the growth rates of companies and countries, while the positive effects on the employment market would become apparent more in the medium and long term. On the other hand, in recent years, scenarios in which AI will play an active role in production systems have gained increasing prominence. In this context, the widespread adoption of AI-based systems in areas such as production planning, quality control, maintenance processes, and supply chain management could accelerate productivity gains and encourage the emergence of new occupations that are complementary to technology. AI taking over routine cognitive tasks will, in the medium and long term, enable human labor to focus more on design, supervision, creativity, and decision support processes. To the extent that appropriate skill transformations can be achieved, this situation could contribute to strengthening the positive effects of the Industry 4.0 process on employment.

With the expected rise of smart factories in the future, a new industrial revolution is anticipated, and in addition to this process, the integration of artificial intelligence (AI) support as a manager has come to the fore. The continuous communication between the technological components included in this production structure via the Internet of Things can significantly increase the flexibility and efficiency of production processes. In addition, it has become possible for a robotic machine learning component that mimics humans with AI to direct and control the production system with a commanding quality. This structural transformation will enable the widespread adoption of personalized production models that can respond more quickly and at lower cost to consumer preferences, while also fundamentally changing the nature of competition between countries and companies.

In this context, competitive advantage will shift away from actors who produce the highest volume or fastest turnaround times, toward those who can deliver the most suitable value for customer demands and possess high technological adaptation capacity. To effectively manage this process, it is critical for policymakers to accelerate investments in more up-to-date digital infrastructure, particularly focused on artificial intelligence; strengthen education and reskilling programs that support human capital in line with this; and create regulatory frameworks that encourage technology-driven transformation in companies. Otherwise, there is a risk that the potential gains offered by Industry 4.0 and AI technologies will remain limited, and that inequalities in competition between economies will deepen on a global scale.

5. CONCLUSIONS AND RECOMMENDATIONS

This study aims to reveal the potential impacts of Industry 4.0 and Society 5.0 approaches on different macroeconomic variables. From an economic perspective, various economic revolutions have occurred throughout the ages, and significant transformations affecting humanity have been the subject of various disciplines. Within the scope of this study, the effects on macroeconomic variables are evaluated holistically, focusing more on certain topics such as growth, income distribution, capital-labor factor shares, and employment dynamics. The findings show that the effects of technological transformation on variables within the economic system are not unidirectional or homogeneous; rather, they demonstrate the existence of many complex relationships with different variables. This is because technological developments involve uncertainties about time horizons, the continuous emergence of new developments, the complexity of institutional structures, and the unpredictable nature of human capital, making it difficult to systematically express economic impacts through a multi-layered structure.

In some cases, replacing labor with machines or robots is easier, especially for routine, low-skilled jobs. Some examples include: innovations in production processes related to the nature of Industry 4.0, the integration of automation and robotics into systems, and the feasibility of integrated production environments through digital integration with developments such as digital technologies and the Internet of Things. As the substitution effect strengthens, temporary mismatches occur in the labor market, and the risk of structural unemployment may increase. On the other hand, based on historical experiences, economic theory approaches show that in the medium and long term, technological progress supports economic growth by increasing productivity and creates a foundation for new job opportunities. In this context, the effects of Industry 4.0 on growth, trade, and unemployment are expected to manifest indirectly and gradually over time through productivity increases, cost reductions, and improvements in global competitiveness.

When evaluated in terms of income distribution and factor shares, it is argued that digitalization and artificial intelligence–based production structures have the potential to generate a bias in favor of capital. In contrast, the labor share of income is expected to be redefined both quantitatively and qualitatively, with the implications of advancements in artificial intelligence becoming clearer in subsequent periods. However, this transformation of labor manifests not as the exclusion of labor from the economic system, but rather as a change in its content and mode of value creation. From this perspective, the Society 5.0 framework emphasizes the integration of technological progress into economies through a human-centered development approach, the preservation of the individual's central role within the economic system, and the realization of these objectives in alignment with a normative vision.

The more effective integration of artificial intelligence into production and decision-making processes necessitates moving beyond the skill-biased technological change approach and increases the relevance of task-based analyses. As emphasized in the study, in determining how developments in artificial intelligence will affect the substitution of labor by robots, the degree of routineness of the tasks performed will be more decisive than individuals' levels of education. This dynamic deepens skill polarization in labor markets while, on the one hand, increasing the importance of non-routine cognitive tasks and, on the other hand, bringing new policy debates to the fore with respect to social cohesion and income distribution.

Within this framework, the transformation of the Industry 4.0 and Society 5.0 processes—reshaped by artificial intelligence—into economic and social gains depends on strengthening investments in human capital, institutionalizing lifelong learning mechanisms, and redesigning social policy instruments in a manner compatible with the evolving structure of the labor force. Positioning artificial intelligence–supported production structures not as mechanisms that exclude the individual, but as tools that complement individuals' capacities for decision-making, creativity, and complex problem-solving, is of critical importance for sustainable growth and inclusive development.

In conclusion, the Industry 4.0 and artificial intelligence–based transformation is neither a process that inherently reduces employment nor one that automatically generates prosperity. The economic and social outcomes of this transformation are directly related to countries' institutional capacities, human capital strategies, and the extent to which they have internalized a human-centered development paradigm. The Society 5.0 approach, with its potential to situate this multidimensional transformation within a human-oriented framework, offers an important reference point for the future configuration of economic and social structures.

The Internet of Things (IoT), big data, machine-to-machine (M2M) communication, and dark factories, which have emerged with Industry 4.0, will profoundly impact economic life. In the coming period, the impact of Industry 4.0 will increase with the addition of Society 5.0 and artificial intelligence. With the innovations brought about by these concepts, computers and production units, which in the past were only connected to each other via the internet, have now become production systems that can communicate with each other, perform analyses, and generate new information. As a result of the communication between the elements in the production process, the collected data will be rapidly shared by these units. Drawing conclusions and offering solutions from the obtained data will be made possible by artificial intelligence. In a sense, artificial intelligence will be a complementary element of Industry 4.0. Adding the opportunities brought by artificial intelligence to this large-scale industrial revolution will create significant impacts not only economically but also socially.

The impact of the robotization process that emerged with Industry 4.0 on employment will vary depending on the acceleration of robotization in industries and the widespread adoption of collaborative robots (cobots). In particular, the use of cobots in industries is still limited. Cobots are compatible with the human-robot interaction concept of Society 5.0. Since Society 5.0 is built upon Industry 4.0, it moves in conjunction with the elements it brings. Therefore, it aims to utilize the digital elements that come with Industry 4.0 to create employment and prosperity. Therefore, the impact of Industry 4.0 on factors such as employment, growth, differences between countries, and the share of capital and labor in production will be related to the extent to which countries can apply Society 5.0 to their production processes. The extent to which Society 5.0 will solve issues such as poverty and income inequality will also depend on how fairly the gains from Industry 4.0 are distributed. In this sense, adaptation to the Society 5.0 concept is also important for countries. With the increased integration of robots and artificial intelligence into production processes, there will be increases in productivity, production, quality, product supply, and many other factors.

Society 5.0 is, in a sense, a human-centered response to the digital systems and robot-focused structure brought about by Industry 4.0. The aim of Society 5.0 is not a system where machines replace humans, but rather an system where machines and artificial intelligence focus on creating value for society, and where machines and humans coexist side-by-side in this process. Future macroeconomic impacts will be shaped by how well Industry 4.0, Society 5.0, and productive artificial intelligence can be integrated with each other, and which of these will dominate the others. Particularly in the production process, the relationships within the triangle of humans, robots, and computers will profoundly affect future economic and social life. Understanding and implementing Society 5.0 will be crucial for solving the macroeconomic problems that Industry 4.0 may bring about. This is because Society 5.0 argues that industrial revolutions alone are not sufficient to increase production; rather, the added value generated by these industrial revolutions must also yield results that benefit people and societies.

Future studies may consider developing standardized indices to measure the macroeconomic impacts of Industry 4.0 and creating international data sets to eliminate data inconsistencies in cross-country comparative analyses.

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