



The contribution of robots to promoting the transition and development of the global economy towards smart production in dark factories

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Abstract ;

In recent years, the use of robots has spread globally in the production processes of fully automated factories known as dark factories. These factories represent a highly advanced technology and an intelligent solution for keeping pace with the dynamic changes of the global economy. The aim of this research is to highlight the contributions of robots and dark factories to the development of the global economy as smart solutions reflecting their integration into production processes. The research concludes that robots are the optimal solution for all productivity problems in the global economy, as they have transformed global productivity from labor-intensive to digital and knowledge-based. This has made dark factory technology the ideal solution for ensuring competitiveness in an environment dominated by advanced technological applications.

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1. Introduction

The global economy has recently undergone a radical transformation, adopting cutting-edge technologies as smart solutions aligned with the Fourth Industrial Revolution. This has led to a shift from traditional automation, where robots were used as production tools, to an era of generative artificial intelligence, granting robots autonomy. This has paved the way for the emergence of fully automated factories, often referred to as "dark factories."

This period has also seen several pressures that have generated changes in global demand. The most significant of these pressures is the demographic growth of the world's population, which has led to increased needs and consequently a rise in the quantity of global demand, while maintaining the same quality and efficiency. This necessitates a solution that keeps pace with this change.

- The main problem of the research :

Based on the above, we propose the following research problem:

How have robots contributed to promoting the transition and development of the global economy towards smart production in dark factories?

- The main hypothesis of the research :

The research hypothesis is based on the main research problem as follows: New technologies have contributed to the development of the global economy by being adopted as smart solutions to various problems it suffered from, most notably robots and dark factories.

-The main objective of the research :

The main objective of the research is to highlight the contributions of robots and dark factories to the development of the global economy as smart solutions reflecting their adoption in production processes.

-The importance of the research:

The importance of the research lies in the contribution of both robots and dark factories as an intelligent engine that moves the global economy from the stage of traditional growth that depends on material and human resources, to a very advanced stage of growth that depends on smart and sustainable efficiency based on artificial intelligence technology and the Internet of Things.

-The methodology used in the research:

The research used a combination of the descriptive method to describe the nature of modern robots and dark factories, and the analytical deductive method to analyze and deduce their contributions as smart solutions in the development of the global economy.

2. The origin and definition of robots

The word "robot" is derived from the Czech word "robota", which means forced labor. And Various sources indicate that the historical evolution of the term robot, follows this chronology:

- In antiquity, the ancient Egyptians invented some models that were relatively similar in their operation to some components of the environment that surrounded them, such as water clocks, and the ancient Greeks also experimented with models of mechanical birds;
- In the modern era, the term "robot" has evolved and emerged as follows:
- With the 1920s, this term became common with the emergence and development of the film industry. Some models that mimicked human behavior were used in some films;
- In 1954, the first robot was invented by "George Devol" who obtained a patent for the "Unimate" robot, which is considered the first programmable robot;
- In 1961, "Unimate" was integrated into the automotive industry. The first company to install it for use was General Motors. The task of this robot was to transport metal parts that had been exposed to very high temperatures. This use is considered the first use of robots in the manufacturing field ;
- The 1960s and 1970s are considered to be years of remarkable development in artificial intelligence, which helped in the creation of the "Shakey" robot by a group of researchers from Stanford University. This robot is considered the first robot capable of moving, adapting and interacting with its environment ;
- From the beginning of the eighties to the present time, and over the course of more than forty years, many fields of technology and communications have developed, which have contributed to the emergence, innovation and introduction of robots in multiple fields of the economy, and even beyond that to the daily use of humans.

The term "robot" has undergone several important developmental milestones, the most important of which are summarized in the following table:

Table 1: Key milestones in the development of the term "robot"

Years	Events
1959	Invention and development of the first robot for industrial use by "George Devol" and "Joseph Engelberger"
1969	-Integration and installation of the first welding and assembly robot at the "Lordstown" plant of "GM" ; - Marketing Unimet robots in the Japanese market
1979	"RE 15", the first six-axis robot of its kind from "Reis", equipped with its own control system, is located in Obernburg, Germany
1988	The first medical device used in hospitals
1999	The German company "KUKA" performed the initial remote diagnostics of robots via the internet
2009	The Japanese company "Yaskawa Motoman" developed a synchronization system for a group of up to eight robots forming a single control system
2016	The first and smallest six-axis robot, "Meca500"

Source: Prepared by the researcher based on: (International Federation of Robotics, 2025).

The robot has been defined in various ways by different researchers, the very most important of which are:

According to the Robotic Industries Association (RIA), it is a "multi-functional, programmable robotic arm designed to move parts, materials, tools, or devices, and specialized in performing programmed movements to carry out a variety of tasks". (Brad kelechava, 2019)

The simplest definition of a robot is "a system that exists in the physical world and acts independently in such a way that it senses everything around it". (Joelle pineau, p. 2)

And according to Merriam-Webster's Dictionary, a robot is "a machine that resembles a living organism in its ability to perform movements independently or even to perform the most complex tasks". (Merriam-Webster dictionary, 2026)

Based on the previous definitions, A robot can be defined as follows. It is "a very advanced machine that reflects the applications of scientific progress in simulating some of the work done by some living or physical beings, and which is programmable to perform it with extreme precision".

The technical advantages of robots that help to increase the productivity of the global economy in an intelligent way are:

- Programmability and Reprogrammability:** The ability to program movements according to requirements without physical modification;
- Versatile:** Adaptable to different requirements if partial physical modification is needed;
- Physical Modification:** Can be physically modified to meet changing global requirements;
- Smooth rotation:** The robots are programmed to perform their tasks with complete smoothness.

3. Benefits of using robots in the economy

The global economic landscape has undergone very rapid developments. Geopolitical changes, a shrinking workforce, increased global demand, and the development of specialization and speed of execution all necessitate that the global economy adopt and integrate robots as a strategic solution to keep pace with all possible changes.

The global economy benefits from the use of robots in production in the following ways: (Bùi Hiếu, 2025)

- The use of robots in the economy leads to a reduction in labor costs:** The use of robots by economic institutions can reduce the overall costs of global production by minimizing labor costs, because robots can perform tasks around the clock, seven days a week, without breaks, sick days, or holidays, without interruption, which greatly reduces the need for intensive manual labor in specific roles. This leads to a noticeable reduction in overall production costs;
- Using robots to improve material and energy consumption:** The use of robots in global production leads to a significant reduction in energy consumption, because the manufacturing institutions are constantly striving to develop them to reduce their energy consumption, since their operation does not require the consumption of energy to provide a suitable environment such as heating, cooling and even lighting. In addition, their high-performance efficiency ensures optimal use of materials consumed for production, especially for the production of products that consume expensive raw and semi-finished materials;
- Robots to improve resource utilization:** Robots are designed to work in a simulated and close manner to workers, and often operate in a much smaller space compared to the spaces used by a worker in normal circumstances, in addition to the tools and machines they use. Moreover, they perform the same work with much more advanced efficiency compared to a worker, and at a very

high speed. They use maximum energy and high efficiency, which leads to a longer lifespan for these robots;

-Using robots increases productivity: Robots are considered tireless workers, unlike human workers. They work continuously without stopping, so they do not need rest periods and do not get tired. This constitutes a major qualitative leap in production. This is clearly evident in the huge quantities of production that cover all global demand;

-The use of robots is based on improving worker safety and reducing work risks: Manufacturing and production environments often pose significant risks to the workforce, through exposure to some hazardous materials, workers suffering from continuous stress due to the difficulty of some working conditions, and their exposure to some serious accidents as a result of using some machines. Therefore, the use of robots is considered the optimal use in these environments, which ensures their safety from all the risks to which they are exposed;

-Using robots offers greater flexibility and scalability in the production process: Robots can be programmed or reprogrammed within the production process to perform multiple tasks, produce several products, or even create new production lines. This makes them more ideal compared to static automation, which is often difficult to reprogram without some physical modifications. Robots can be reconfigured by businesses to produce new products within hours or days, unlike static automation, which can take weeks or even months. This gives robots a competitive advantage for reducing downtime and maximizing resource utilization ;

-Using robots enhances competitive advantage: Using robots in production helps organizations gain a competitive advantage by being able to produce high-quality products at very low costs, and bring them to market quickly.

4. The development of robotics in the global economy as a smart technological solution

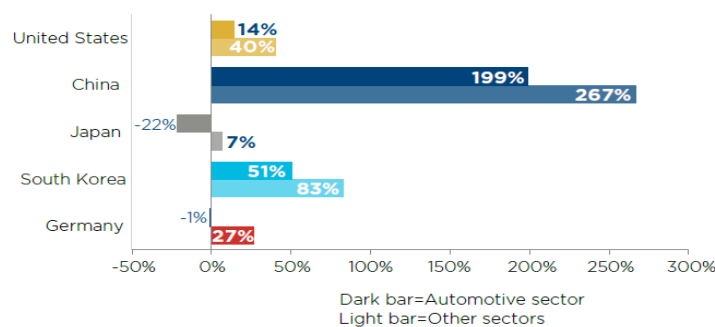
The increased use of robots in production worldwide is due to the following main reasons: (OXFORD ECONOMICS, 2019, p. 16)

-The significant decrease in robot costs: The large and rapid expansion of the use of robots in global production is due to the significant decrease in the production costs of this machine, which is centered on the large growth in the ability to process electronic chips, the increase in battery life, and a significant decrease in well in other components of robots, and the continuous decrease and development in the integration of smarter software to control robots. This decrease was estimated between 2011 and 2016 at a rate of 11%, and the tendency of economic institutions to use robots in production due to the steady increase in labor costs in major economies worldwide, most notably

Korea, Japan, the United States, and Germany, with an average unit of work at 65 percent in 2008, in addition to the aging of the workforce in these countries ;

-Significant technological advancements have led to faster robots: With technological advancements, the production of robots used in global manufacturing has become highly sophisticated. Most importantly, they have become smaller in size, faster, and more precise in performing their assigned tasks. Furthermore, by integrating artificial intelligence, they have become more intelligent, sensing their surroundings to make decisions within their designated scope. This has led to their widespread adoption and acceptance by sectors outside the automotive industry, which remains the largest global consumer of robots. This is illustrated in the following figure.

Fig 1: Percentage of robot use intensity in production for the world's most developed economies for the period 2011-2016

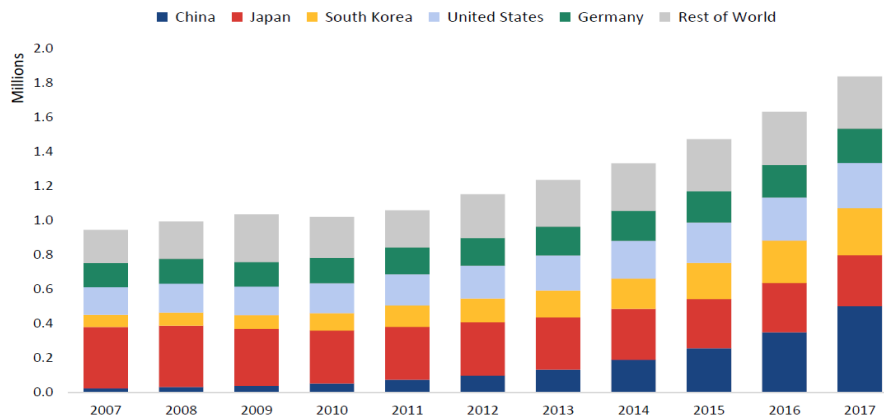


Source: (OXFORD ECONOMICS, 2019, p. 16).

-Increased demand for more manufactured goods: Over the past two decades, China has become the world's factory, supplying it with a wide variety of industrial goods. It is the world's largest manufacturer of automobiles and the largest producer of electronics, lithium batteries, and communication technologies. These sectors, with their high demand for their products, are also the most frequent users of robots. Furthermore, China is a global leader in automating its most productive and globally in-demand economic sectors.

The increased use of robots by the world's most developed economies is due to the reasons mentioned previously. Robot installation figures for 2017 are summarized in the following figure:

Fig 2: Number of robot installations worldwide for the period 2007-2017



Source: (International Federation of Robots, 2019).

The previous figure shows that, globally, five countries lead the world in the number of robots installed for use in the production process. China installed 501.185 robots, topping the list; no other country installed as many. Japan followed with 297.215 robots, then South Korea with 273.146, the United States with 262.058, and Germany with 200,497 in 2017. These countries account for 72% of all robot installations worldwide. (SELECTUSA, 2020, p. 4)

According to previous statistics, in 2003, the average value added across all industrial sectors globally was \$764 billion, with an average of 661 million working hours and a robot density of 2.0 robots per million working hours. Between 2003 and 2017, the average increase in robot density was 2.0 robots per million working hours, increasing the value added of robots across various manufacturing sectors worldwide by 4%, equivalent to US\$700 billion. Notably, there was no change in the number of working hours. Looking at the sectors, the automotive and transportation industry saw the largest increase in robot density, reaching 15.1 robots per million working hours. Conversely, the mining and quarrying sector experienced the most significant growth during this period in robot productivity in the production process. (SELECTUSA, 2020, pp. 5,6)

Based on the above, the analysis demonstrates a direct and positive relationship between the density of robot use in the global economy, as a highly advanced and intelligent technology, and the productivity of the global economy. This means that if the global economy increases its use of robots in the production process, it will have a positive impact on its productivity. A 1% increase in the density of robots in the global economy is associated with a 0.0% increase in the expected marginal productivity. (SELECTUSA, 2020, p. 10)

5. Definition, Components of dark factories and their relationship to robots as intelligent and highly advanced technologies

The relationship between technological development and dark factories is both causal and complementary, dark factories are not just ordinary factories, but are a necessity for a different set of technologies and techniques to reach the stage of maturity and actual application in production methods.

Although the term "dark factories" is a relatively recent term, it has been given some very important definitions, including:

-Dark factories are fully automated organizations that operate without human workers in the production process, working around the clock using industrial robots, automated machines and artificial intelligence technology, without consuming or needing lighting, heating or any conditions suitable for human work. They are also called extinguished factories and represent the most advanced stage of factory automation ; (TRACTIAN, 2026)

-Dark factories are production or logistics facilities run by machines and robots, operating autonomously and with highly advanced digital technologies. The part of the name "dark" indicates the possibility of operating without light or with a minimal amount of light, which is a condition for the operation of some sensors and cameras. There is no need for workers. These factories are designed for production with maximum efficiency and production accuracy, using modern and advanced technologies around the clock ; (SCIO AUTOMATION, 2025)

-The term "dark factories" refers to fully automated facilities that operate without worker supervision or intervention. The term "dark" refers to the absence of any lighting for human operation, allowing these factories to operate autonomously in complete darkness. (TEMAS, 2025)

From the preceding definitions, the Components of dark factories are summarized in the following table:

Table 2: The components of Dark Factories

component	role
Industrial robots	Handle assembly, welding, painting, machining, and material handling tasks with precision and repeatability
AGVs and AMRs	Transport raw materials, work-in-progress, and finished goods between stations without human intervention
Computer vision / AI inspection	Detect surface defects, dimensional errors, and assembly mistakes at production speed
IIoT sensors	Monitor temperature, vibration, current, and other parameters across all equipment in real time
PLCs and DCS	Control machine sequences and coordinate production processes automatically
AI and machine learning	Optimize scheduling, detect anomalies, predict failures, and adapt processes without human input
Digital twin	Simulate production and asset behavior to test changes and predict outcomes before applying them to the physical environment
Industrial robots	Handle assembly, welding, painting, machining, and material handling tasks with precision and repeatability

Source: (TRACTIAN, 2026).

From the previous table and in agreement with all the research conducted on dark factories, dark factories are not established, nor can we talk about them and about large-scale production to keep up with the terrible increases in global demand without integrating robots into the production process. That is, for dark factories to exist as a smart solution to cover excess orders, we must be able to provide robots capable of doing so.

The relationship between robots and dark factories can be summarized as follows, dark factories are an inevitable consequence of the existence of robots. Dark factories are not merely buildings, but rather operational environments. This state of affairs is only achieved through the independent intervention of robots with minimal human intervention. Without robots, dark factories would become traditional factories managed by humans. Robots are the reason for the existence and emergence of dark factories, and the reasons for this relationship are:

- The difficulty of human labor in some production environments. Using robots in dark factories completely solves this problem, thus increasing production density and utilizing the total area of the dark factories with high efficiency;

- The autonomous ability of robots resulting from technological development. The development of technologies, especially artificial intelligence, has given robots the power to operate in dark environments with intelligence and relative independence ;
- The development of robot production and the decrease in their prices and maintenance costs. Previously, robots were expensive, their maintenance was costly and involved human intervention. With the development of their production methods by integrating modern technologies and controlling their production costs, their prices have become very reasonable, and they have become efficient in making dark factories competitive and profitable compared to traditional factories.

6. Robotics as a solution for smart production, contributing to the development of the global economy in dark factories

The global economy has developed tremendously in production methods by adopting robots and dark factories, moving from traditional linear production to smart electronic production. This development in global production has not changed the way production is done, but rather how and when production takes place.

The previous development of global production, in quantity and quality, was contributed to by robots and dark factories, which are among the modern technologies and methods for developing production processes. These contributions are summarized in the following points:

-Global expansion and market size: At the beginning of the millennium, robots only performed heavy tasks such as car manufacturing. With the development of robot production methods through the integration of advanced technologies, they became more flexible. Through them, production moved from the automotive industry to other sectors such as food industries, electronics, and even the textile industry. This transition and development became possible by increasing the density of robots in the production process to reach an average of 162 robots globally. According to the International Federation of Robotics reports for the period 2005-2025, the development of the spread of robots and dark factories globally is as follows:

-Regarding the spread of robots and their integration into the global economy for this period, it is divided into two periods. The first, from 2005-2015, was characterized by stability and slowness. During this period, it was a set of auxiliary tools. In the period from 2015-2025, the spread doubled enormously as a result of the maturation of modern technologies, most notably the Internet of Things and artificial intelligence, which helped in the emergence of dark factories ;

-According to 2025 statistics, the distribution of adoption of dark factory technology by sector is as follows: the automotive industry 42 percent, which uses it because it is considered a heavy

industry and needs it to accomplish some difficult tasks; electronics 28 percent, which uses it to accomplish jobs that require high precision that workers cannot accomplish; the food and chemical industries 15 percent, because they rely on environments that are mostly harsh and cannot be endured by humans and are performed by robots; and 15 percent for the remaining industries such as pharmaceuticals and textiles.

-The shift in global production from simple automation to intelligent production: Robotics and dark factories have facilitated the global economy's transition from minimally automated factory production to full automation. This is achieved by integrating artificial intelligence and the Internet of Things (IoT) for intelligent, self-regulating production capable of making decisions, correcting errors, and producing in large quantities with exceptionally high quality and precision. Global production has moved from rigid automation with robots performing single actions, to sensor-based robots equipped with sensors that stop working when they encounter an obstacle, to dark factories operating with AI-powered robots capable of self-learning to make autonomous and intelligent decisions and correct errors ;

-Using resources efficiently to achieve sustainability: Global production is evolving with the use of robots and dark factories as a smart and environmentally friendly solution. This is achieved by saving and rationalizing energy use, as dark factories and robots use 20% less energy than usual. They also protect the environment by minimizing waste to a level known as zero waste. All of this is moving global production towards sustainability ;

- The Global Development of Robotics and Dark Factories: According to the International Federation of Robotics, global productivity growth is expected to increase from 0.8% to 1.4% annually between 2025 and 2030, driven by robotic automation. Investment in dark factories is projected to grow at a compound annual growth rate (CAGR) of 8.5%.

7. CONCLUSION

The relationship between robots and dark factories is no longer simply one of the tools used in the workplace, but rather an integrated one that has led to the emergence of a new and highly advanced production model that often surpasses human capabilities. Therefore, robots are considered the smart solution to all productivity problems in the global economy, having shifted global productivity from a labor-intensive to a digital and knowledge-intensive one. This has made dark factory technology the ideal solution for ensuring competitiveness in an environment dominated by highly advanced technological applications. This confirms and reinforces the hypothesis upon which the research is based.

The research paper reached the following conclusions:

- With the modern and advanced applications of technologies in contemporary global production methods of the Fourth Industrial Revolution, robots are considered the driving force of dark factories. Without robots, automation would be merely an auxiliary tool and not an independent system. Robots help in the establishment of dark factories, which are the most important forms of operational independence for global production and the development of the global economy ;
- By adopting robots and dark factories as smart solutions, the global economy benefits from cost efficiency. Using them reduces global production costs by more than 30%, and waste is minimized, sometimes even eliminating waste altogether ;
- Robotics and darkroom technologies have enabled the global economy to undergo a geographical restructuring. Previously, industries migrated to countries with cheap labor, primarily China. These technologies have allowed for control over production costs and have even enabled some countries to relocate factories that had previously moved due to economic circumstances, leading to a repositioning of economies ;
- Robots and dark factories have contributed to an average annual increase in global productivity rates exceeding 1%. This is due to the adoption of robots and dark factories by several of the most advanced economies to keep pace with evolving global demand in quantity, quality, and precision.

Based on the preceding results, several recommendations are suggested :

- Reskilling the workforce by investing in training courses and programs that equip them with the advanced technological skills needed for robotics and dark factories is essential to keep pace with the radical transformations of the global economy ;
- Providing legal cover for both the operation of robots and the work of dark factories to ensure their security and the security of their data from cyber breaches and thefts, and to protect the intellectual property of the big data they generate as a result of their activity;
- Supporting innovation projects associated with smart and flexible robots to achieve full automation of dark, self-run factories, to ensure self-sufficiency in dealing with all problems by making decisions to solve them, which contributes to the technological development of the global economy, by applying it in various other sectors.

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