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Political Economy of Technological Revolutions

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Abstract

The object of the research is the logic of technological revolutions, and its subject is the complex systemic interaction between the technological, economic and political subsystems that significantly shape the entire political-economic system. The object and subject of the research predetermine its purpose, which is to uncover the broader picture of the overall political-economic transformation that occurs with each subsequent technological revolution, particularly in the context of the ongoing Fourth Technological Revolution. This goal necessitates a political-economic approach to the research, one that facilitates the understanding of the logic behind systemic change. The approach emphasizes the study of three key factors – technology, economy, and politics – and the intricate interactions between them in the shaping of the political-economic systems at various stages of capitalism's development. Consequently, the research is structured to first establish a general methodological framework for the political economy of technological revolutions, then to conduct a systemic analysis of the evolving interactions between technology, economy, and politics, and finally to explore how these elements transform the overall political-economic system. This topic is particularly relevant amid the ongoing changes brought about by the Fourth Technological Revolution, highlighting the urgent need for a comprehensive theoretical framework to understand these developments and prevent potential catastrophic outcomes. Inevitably, there are limitations due to the vast scope of interrelationships under investigation and the constraints of addressing them fully within the publication's requirements. These limitations do not undermine the overall validity of the conclusions, as the identified causal and functional relationships do not diminish the findings or the contributions made toward establishing a unified paradigmatic framework. This framework serves as an "ideal type" for understanding technological revolutions within the context of the ongoing Fourth technological, rather than focusing on specific instances or manifestations of related phenomena.

Keywords: technological revolution, technology, economy, politics, political economy

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1. Introduction

In recent years, a new academic discipline has emerged: the political economy of scientific research and innovation. This discipline examines the political-economic dimensions of knowledge production, distribution, and consumption, exploring their interrelationships with politics and the economy and how they shape different political-economic models (Tyfield et al., 2017).

It is not a coincidence that a substantial body of literature addressing the political economy of various technological revolutions and processes is emerging. Recent works include titles such as Critique of Digital Capitalism: Analyzing the Political Economy of Digital Culture and Technology (Betancourt, 2016), Political Economy of Science, Technology, and Innovation (Martin, 2000), Political Economy of Support for Technologies (Torvanger et al., 2011), Political Economy of Agricultural Biotechnology Policies (Graff, 2001), Global Political Economy of Technological Standardization: The Case of the Korean Mobile Communications Market (Jho, 2007), Contribution to the Political Economy of Google (Fuchs, 2011), Political Economy of the Mass Press: Legitimacy and Technological Change in the Ottoman Empire (Cosgel et al., 2012) and many others.

The field encompasses an extensive range of scientific literature and academic courses, with research and teaching conducted across different levels within various political economy disciplines. Examples include Political Economy of the Internet (Fuchs, 2009), Political Economy of Innovation (Cowhey et al., 2009), Political Economy of Technological Innovation and Employment (Huo et al., 2010), Political Economy of Technology Support (Torvanger et al., 2011), Global Political Economy of Technological Standardization (Jho, 2007), and Political Economy of Information (Mosco et al., 1988), among many others.

These publications address specific political-economic issues that arise from technological development, whereas the present work adopts a more holistic approach. It is based on the understanding that the evolution of any given technology is not solely driven by economic incentives or the independent advancement of human knowledge, but is also significantly influenced by an increasing number of political and social factors.

Firstly, throughout the development of modern capitalism – and with it, political economy – technological policy has consistently been a crucial element in the economic growth of nations. This role is expanding, as evidenced by the emergence of numerous state institutions and legislative frameworks dedicated to the development and regulation of technologies, as well as related scientific research and education. These developments are closely tied to the policies and strategies concerning science and technology, as well as to the specific characteristics of the economic system at various stages of its evolution. Technologies may be discovered, as was the case with gunpowder and printing in China, but if the economic system does not require them, they may not become integrated into the economic structure. However, when these technologies were later rediscovered in Western Europe, where capitalism was emerging, they quickly became competitive advantages and brought about accelerated development.

Secondly, the introduction of a new technology often triggers consequences that can alter not only the economic sphere,

but also the entire social system, and these changes inherently carry political-economic implications. For example, the advent of gunpowder concentrated the means of violence in the hands of monarchs, facilitating the rise of absolute monarchies, modern armies, and the formation of modern states. Similarly, the printing press revolutionized communication, laying the groundwork for modern propaganda, transforming the cultural and public spheres, accelerating educational development, and reshaping the values of large segments of the population.

This underscores the necessity and feasibility of applying a political-economic analysis to technological development. Such an approach begins with an understanding of the close systemic interactions between technological, political, and economic factors, which are connected through numerous direct and indirect links. This systemic political-economic perspective on technological revolutions is crucial for the explanation of the developments during the ongoing Fourth Technological Revolution. Given the vast array of these connections and the profound systemic changes they bring about, it is impossible to consider them in their entirety. This necessitates certain limitations in the study, including the need to justify the systemic approach. This approach provides the methodological foundation required to comprehend the logic of technological revolutions, including the ongoing Fourth Technological Revolution, and to uncover the nature of the interrelationships between technology, politics, and economics.

2. Methodological principles and the role of the systemic approach

To explain the political economy of the Fourth Technological Revolution, it is essential to consider a common critique in social sciences known as "technological determinism," which typically refers to two key ideas. First, it suggests that technology is viewed as a primary driver of social change. Second, it implies that technology is considered in isolation from society, despite its significant impact on social dynamics (Webster, 2004). This impact has grown with each technological revolution, bringing both positive and negative consequences. Technologies enable radical changes in the production, exchange, distribution, and consumption of goods, as well as improvements in the organization and management of social processes. However, an important – and often dominant – driver of technological development since the Middle Ages has been the pursuit of profit and the quest for competitive advantages by capital, a drive that has been further intensified by the active role of the state in these processes.

On the other hand, technological determinism gives rise to two contrasting mass responses. The first is technological optimism, which suggests that technology itself will lead to a fundamentally new society – a belief often seen at the onset of every technological revolution. For instance, at the beginning of the Third Technological Revolution, there was widespread talk of entering a "third wave society," "post-industrial society," "information society," "knowledge society," or "network society," all perceived as distinct from both capitalism and socialism. Similarly, as Web 2.0 emerged at the end of the Third and the beginning of the Fourth Technological Revolution, there were predictions of a society characterized by Internet freedom, where traditional power dynamics would dissolve, allowing everyone to freely express and present themselves. However, in recent years, public attitudes have shifted toward

technological pessimism. Concerns have grown about how digital technologies are becoming tools of total control wielded by global corporations, how we are moving toward a world dominated by "fake news," "post-truth," hybrid warfare, and manipulation. In this world, millions or even billions of people are vulnerable to cyberattacks, and new technologies bring with them a growing array of dangers that could prove catastrophic for humanity.

The thesis I put forward here rejects the form of determinism that views technology as something separate from society, exerting a defining influence on development regardless of whether that influence is perceived optimistically or pessimistically. While technology can have positive outcomes – such as transport technologies, which have dramatically increased the movement of people and goods worldwide – there are also negative consequences. For instance, approximately 1.19 million people die in traffic accidents globally each year, making them the leading cause of death for young people aged 5 to 29. Additionally, 20 to 50 million people suffer injuries, some resulting in permanent disability (World Health Organization, 2023). This dual nature of technological impact necessitates state intervention through regulations and the creation of institutions to mitigate negative effects. The development of technology is thus inevitably linked to new regulations and institutional frameworks. Legal systems evolve to accommodate various labor, tax, and securities laws, as well as laws governing interactions with technology, criminal codes, and more. Moreover, the more advanced the technology, the more significant its positive and negative consequences, which in turn require increased regulation and the establishment of new institutions.

Technologies are deeply integrated into various subsystems of society, interacting with the economy and other aspects of social life. While society is a dynamic system, and there are periods when the influence of technology may become dominant, it is never the sole factor in societal development. Therefore, a political economy of technological revolutions must be grounded in several fundamental methodological principles.

First. The principle of the co-evolution of technology and knowledge. The introduction of production technologies changes a basic characteristic of society, such as its productive forces – and the means of production and the knowledge, skills, qualifications, experience and work habits of men – so called subjective factors of production. This has corresponding consequences for the changes in the organization of production, its dimensions and characteristics, exchange, distribution, consumption. It is inseparable from the development of science and education, through which new knowledge is created, necessary for the production of the relevant technologies, and this production, in turn, creates new technologies that become a tool for the development of knowledge - starting with the appearance of the telescope and the microscope and finishing with the modern research laboratories. The increasing amount of technology is becoming a kind of embodiment of the increasing knowledge known as "universal intelligence".

Second. The principle of universal interconnectedness. Technology is not an isolated sphere. Rather, different types of technology impact, to varying degrees, all aspects of society – encompassing production, social relations, organization, communication, identity formation, and power structures. Understanding technology

is crucial for grasping the functioning of culture, the formation of social communities, the evolution of identities, and the development and influence of the state. The nature of social structuring changes across different technological revolutions: each revolution – First, Second, Third, and now the Fourth – introduces distinct dynamics and dependencies. Moreover, each successive revolution intensifies the systemic dependencies related to technology. The Fourth Technological Revolution, in particular, exemplifies the highly convergent nature of digital technologies, which now interlink previously disparate activities and elements across individual communities, nations, and the global population (Schwab, 2016). Today's interconnectedness means that a single individual can transmit information, carry out destructive attacks, commit fraud, and engage in various other activities anywhere in the world – actions that would have been deemed impossible in the past.

Third. The principle of systematicity. Insofar as technologies are embedded within systemic relationships with the economic subsystem and the overall functioning of the society, they cannot be seen as either singular or one-way determining factors. Technologies emerge from interactions with other societal subsystems, and changes within them lead to transformations in these subsystems and in society as a whole. A typical example of this phenomenon is the rise of significant and highly impactful technologies, which often provoke initial euphoria about their potential and lead to substantial investments by companies. This can result in stock market bubbles and temporary economic crises. Historically, this pattern has been observed with railway technology in 19th-century Great Britain, where the anticipation of rapid profits led to a stock market bubble. Similarly, the "dot-com bubble" of 1997-2000 was driven by overoptimistic expectations of quick returns from Internet technologies. Currently, there are concerns about a potential bubble driven by significant investments in artificial intelligence startups (Floridi, 2024). Such developments have profound economic implications and complex consequences for societies as a whole.

Fourth. The principle of the inevitable state. The development of technologies results from both market forces and state involvement. On one hand, market competition drives technological advancement, as technologies are crucial competitive assets. On the other hand, state support and technological policies play an indispensable role. This is valid for Alexander Hamilton, one of the founding fathers and the first U.S. Treasury Secretary, who articulated the state's role in industrial development in his 1791 "Manufacturing Report" to Congress. Hamilton advocated for subsidizing and protecting industrial companies and even suggested using industrial espionage to acquire advanced technologies from other countries, particularly from Britain, where the First Technological Revolution had begun. Successful economic development requires a combination of state strategy and market forces (Hamilton, 1791). Key discoveries are often first made by government institutions and later adopted and developed by private market entities. Some of the biggest discoveries like the early development of the Internet, microelectronics, space technologies and nuclear research were driven by government-funded military research before being commercialized. Conversely, emergent market technologies are often accelerated through military use, state-sponsored initiatives, and

relevant subsidies and advantages provided to companies. Thus technology policies are crucial in the introduction and diffusion of technology. These policies are influenced by various factors, including the need for national economic development, the role of technology in military power and security, and the need to address emerging risks such as climate change. This is why the states now are increasingly focusing on stimulating the development of climate technologies for renewable energy, circular economy, and sustainable development. Technologies are integral to a nation's critical infrastructure, and their failure or destruction can significantly impact national economic security and other societal subsystems. To address the risks the USA Cybersecurity and Infrastructure Security Agency (CISA) was established to safeguard 16 critical infrastructure sectors, recognizing the importance of these sectors to national security, healthcare, education, and more.

Fifth. The principle of institutional change. Every technological revolution necessitates the development of new institutions, regulations, and control systems. The introduction of the railway in the 19th century required the establishment of a comprehensive ecosystem encompassing innovation, professions, organization, regulation, planning, and coordination. This included planning the transfer of goods, managing transitions between different railway lines, implementing technological standards set by the state, and eventually internationalizing these standards. Railway stations and train traffic rules were created, and states developed institutions to oversee and manage these processes, establishing management hierarchies and functional specializations. This led to the emergence of what is known as sociotechnical systems, which integrate technological processes of production with labor organization and institutional structures. Sociotechnical systems require high precision in time, organization, and management. Today, this concept is evident in large technology companies, as illustrated by studies on the political economy of firms like Google. Such companies are seen as complex technical systems that integrate hardware and software into global platforms. Google combines various software components – such as email, web browsers, data collection and processing tools, search engines, algorithms, artificial intelligence, and cloud technologies – with the necessary hardware, primarily data centers. These software and hardware systems are interconnected with millions of users, enabling personalized data consumption and collection. The entire organization of the company's operations is driven by this technical system, shaping its functionality and interaction with users (Rieder, 2022).

Sixth. The principle of the changing political economy. Every technological revolution produces technologies that transform not only economics, but also politics, ideologies, educational systems, regulations, and mechanisms of power and social control. These technologies significantly impact economic and political realities, transforming the relationship between economics and politics, as well as the broader political-economic system, thereby giving rise to new theories aimed at describing and explaining these emerging realities. The advancement of technology brings about radical changes in market interactions, factors of production, accumulation opportunities, and the production, exchange, distribution, and consumption of material goods, services, as well as knowledge and information.

Technological progress not only generates new jobs, professions, products, but also increases the volume of goods produced, creates new professional skills, and generates employment opportunities necessary for producing these new goods. Each technological revolution alters distribution relations by creating conditions for a rapid increase in income and wealth for certain social groups while decreasing them for others. This shift leads to social inequalities, conflicts, and a need for state intervention to regulate these processes, which influences state policies. Additionally, technological advancements transform exchange relations through new transport technologies and methods for moving commodity flows. This transformation necessitates changes in consumption patterns, which requires the implementation of new policies, mechanisms, and institutions to facilitate the realization of these goods. Such changes can occur at the international level through technologies that enable rapid transfer and relevant trade policies of countries, or at the national level through the creation of economic and social mechanisms designed to stimulate consumption by a large number of people.

Seventh. The principle of the shrinking space and accelerated time. Technological revolutions contribute to the increasing complexity of societies and social processes, accelerating the exchange of data and information. At the same time, they offer new opportunities for control and management of social processes by the states and companies, enhancing feedback mechanisms through improved information, communication, and transportation networks. Each subsequent technological revolution facilitates more efficient management of market interactions and large commercial networks by introducing innovations such as the telegraph, the telephone, mail, mobile phones, internet and a growing array of communication applications and networks. They lead to the shrinking of space and facilitate all forms of socio-economic interactions, which now unfold in real time, creating a sense of exponential living. Changes that previously occurred during entire generations now emerge within days or weeks. This highlights the critical importance of rapid responses to an ever-growing number of variables, posing a significant challenge. These responses have varied across different technological revolutions. Today, in the era of the Fourth Technological Revolution, the role of "big data" and algorithms is becoming increasingly prominent, revealing vast amounts of previously hidden information and laying the groundwork for enhanced societal control.

Eighth. The principle of the growing information. Each technological revolution brings about changes in the overall functioning of a country's information systems and those of the individual institutions. Nations establish ministries dedicated to the development of various industries and technologies, evolving from the Ministry of Heavy Industry and Ministry of Chemical Industry during the Second Industrial Revolution to contemporary ministries focused on Electronics, Innovation, and Artificial intelligence. In the First and Second technological revolutions, libraries for mass use, as well as reporting and documentation systems in various institutions, were primarily paper-based. With the Third and Fourth technological revolutions, the capacity to collect and store information expanded significantly due to the advancements in digital technologies, such as computer memory and various types of storage devices. Each stage has marked a qualitative leap in

the ability to process increasing volumes of information and manage responses in real time. Each technological revolution has led to an accelerated increase in the production of information, stored in new forms and via new media. From the beginning of the New Era to 1500, when Gutenberg's printing press had been in operation for over half a century (invented in 1439), the information created by humanity doubled. This pace continued to accelerate and by 1973, as the Third Technological Revolution gained momentum, the total amount of information was 128 times greater than at the start of the New Era (Motsev, 2001). By 2013, it became evident that the volume of data, information, and knowledge available to humanity was doubling every 13 months. With the advent of the Internet of Things, this process accelerated dramatically, with information now doubling approximately every 12 hours (Schilling, 2013).

Ninth. The principle of transformation through information. Information is not only growing, but its growth is changing the world around us. Each new stage of technological advancement introduces innovations in transportation, communication, and military technologies, which have significant implications for the political-economic system. Transportation and communication technologies reduce transaction costs in the economy. Transportation technologies accelerate the movement of people within nation-states, fostering increased systemic interdependence between different regions of a state. This, in turn, leads to the creation of new professions, professional organizations, laws, and institutions. The advent of the automobile gave rise to new professions such as drivers, car service specialists, transport experts, and transport police, along with corresponding laws and institutions related to road traffic. A similar transformation occurred with the introduction of the railway and is now evident with the development of self-driving cars. Communication technologies also bring about radical changes in interactions between people and social subsystems, affecting the functioning of each person and society as a whole. They enable faster collection, processing, and dissemination of information. Today, thanks to the Internet, virtually all of humanity operates within a unified communication space, allowing people to exchange information globally. Language barriers have diminished, as information can be shared through Internet memes or translated with tools like Google Translate. This allows everyone to create, disseminate information, and influence or be influenced by others, marking a significant leap in human relationships and interactions.

Tenth. The principle of strategic development. The successful development of a country, including its acceleration and ability to surpass others, largely depends on its capacity to formulate and implement an effective strategy for the development and adoption of new technologies. This includes industrializing with cutting-edge technologies across various economic sectors and preparing or attracting the necessary skilled personnel. Poverty, for example, in less developed countries is strongly correlated with a lack of socio-economic dynamism, where technology plays a crucial role. Countries that successfully create strategies, models, institutions, and engineering talent often experience accelerated progress and catch up with more advanced nations. For instance, Japan's rapid rise in the late 19th century, the post-World War II success of the "Asian Tigers" (South Korea, Singapore, Hong Kong, and Taiwan), and the industrialization

strategies employed by the USSR after the 1920s and Eastern European countries after World War II exemplify this trend. China has notably executed a successful strategy in recent decades, while India, after establishing five-year development plans and appointing its first Minister of Commerce and Industry in 1947, has been catching up, surpassing Great Britain in recent years and is expected to soon become the third-largest economy in the world (Silver, 2024). Such progress is reshaping not only the global economic landscape but also the balance of economic and military power. This competition for leadership in the global economy has prompted both the USA and the EU to emphasize the active role of the state in "re-industrialization" efforts, reversing the trend of offshoring industrial production to countries with lower labor costs that occurred during the era of globalization.

Eleventh. The principle of crisis management. Successive technological revolutions do not emerge spontaneously. They are the result of the evolution of the economic and social systems within countries, where previous profit factors become exhausted, leading to crisis processes. Technologies serve as a crucial tool for overcoming these economic crises. Moreover, because they provide significant competitive advantages, a political economy of technological development becomes relevant. At every stage of modern state development, the policies of the state play a pivotal role in the deployment of new technologies. For example, the First Technological Revolution cannot be separated from the role of the British state, which sought to protect and retain emerging technologies within its borders. Similarly, the Second Technological Revolution's development strategies were deeply intertwined with American state involvement during the World Wars. The Third Technological Revolution's growth was significantly influenced by American state initiatives, such as the development of the Internet from its military origins as ARPANET to the expansion of "electronic highways" in the 1990s under the Clinton administration. This pattern is evident in any technological revolution. The more technologically backward a country is and the faster it wants to accelerate its development, the more the state becomes a dominant force in this process. In developed Western countries, there is often a dynamic interaction between the state, the market, and technology. In contrast, in state-socialist systems like the Soviet Union, the state played a central role, with the market being less significant, as the leaders of these societies sought to rapidly catch up with more advanced nations.

Twelfth. The first-come, first-served principle. Countries that are the first to create and deploy technological innovations gain significant competitive advantages, which in turn alters their geopolitical, geoeconomic, and military power and roles. For example, the First Technological Revolution propelled Great Britain to global prominence and established it as a global power. The Second Technological Revolution contributed to the geopolitical, geoeconomic, and military ascendance of the USA and Germany, setting the stage for the First World War as a contest for a new global order. The Third Technological Revolution led to the rise of Japan and caused concerns in the US about Japan potentially surpassing it, resulting in the "Plaza Accords," which pressured Japan to adjust its currency strength and reduce its competitive advantage. Currently, the Fourth Technological Revolution is fostering the growing power of China and initiating a geopolitical and geoeconomic rivalry

between the US and China. This rivalry has spurred research into the "political economy of the US-China technology war," focusing on areas such as semiconductors, artificial intelligence, and rare metals (Zhao, 2021). The technological competition also drives deglobalization trends and emphasizes issues of state sovereignty. For instance, the concept of digital sovereignty is becoming increasingly important, as countries seek to prevent foreign technology companies from collecting data on their citizens or disseminating information within their borders. Additionally, technology is enhancing the ability to close borders and shorten value chains, with innovations like 3D printing playing a crucial role in bringing production back to national territories.

3. Systemic consequences of the development of technologies

The systemic interconnectedness of technologies with various societal components is exemplified by the concept of infrastructure. The 1996-1997 US Commission on Critical Infrastructure Protection (PPCIP) identified key components of infrastructure, including water supply, oil and gas extraction and storage, emergency services (ambulance, fire departments, disaster response), government offices, financial institutions, electricity, and information and communication systems. As noted, "By infrastructure...we mean a network of independent, mostly private, man-made systems and processes that jointly and collectively work to produce and distribute a continuous flow of goods and services" (Edwards, 2003). Infrastructure has become a hallmark of the modern state, particularly since the First Technological Revolution. Technologies from this era, such as centralized water supply and heating, laid the foundation for modern infrastructure. The Second Technological Revolution further advanced this with developments like highways and power grids. These technologies form an interconnected network that integrates almost all elements of the social system, encompassing technological, economic, political, and social networks. This integration transforms everyday culture and enhances the overall functioning and capabilities of a society, including its economic, political, and military power.

The emergence of various systems and subsystems in society is a direct result of technological integration. Initially, these are technical systems, which involve the operation of specific sets of machines and devices. These are then overlaid with newly developed socio-technical systems. For example, since the 19th century, the management of railways has been a prime example of a socio-technical system, encompassing ministries, agencies, and institutions overseeing railway operations. Such systems constitute transportation infrastructures managed by relevant transport ministries and governed by numerous regulations. Additionally, there are man-machine systems, which include machines and their operators. For instance, this could be an airplane with its crew or a nuclear power plant with its workforce. These systems integrate human and machine elements to perform complex functions. Industrial corporations form economic-technical systems that, with globalization and the expansion of global value chains, evolve into global systems. A notable example is the automobile industry, where major corporations operate on a global scale, coordinating complex international supply chains and production networks.

Different technological revolutions vary in their relationships with societal subsystems, the volume and speed of wealth they generate,

and their overall impact on society. These revolutions can influence societal subsystems either directly or indirectly through the economy and associated technologies of production.

3.1. Systemic implications for power and politics

Technologies impact power relations directly and indirectly, influencing politics, the state, and through them, economic regulation, the redistribution of manufactured goods, and the management of market contradictions. This, in turn, affects the implementation of various economic policies. The technological capabilities available to Henry VII, Stalin, or contemporary leaders like Biden or Putin shape their ability to exert influence and drive economic and political agendas differently.

From the works of economists such as John Galbraith, we understand that there are three main types of power: coercive (punitive) power: this type of power is based on the ability to impose penalties or sanctions; compensatory (economic) power: this type involves the distribution of economic benefits or rewards; conditional (ideological) power: this type is rooted in the ability to influence or shape beliefs and ideologies (Galbraith, 1993).

Social scholars like John French and Bertram Raven identify six types of power: rewarding power: the ability to provide desirable outcomes or rewards to individuals; coercive power: the use of fear or threats to control behavior; informational power: power derived from possessing knowledge that others do not have, enhancing one's opportunities; legitimation power: power that arises from mutual agreements on roles and obligations, which confer authority; expert power: power based on specialized skills or knowledge, such as expertise in digital technologies (Staley, 2016).

Different historical periods and contexts shape how these powers are concentrated and exercised and the evolution of political economy reflects the changing technological capabilities through which these types of power are concentrated and exercised.

In the first stage, before the First Technological Revolution, three key technologies radically transformed power in the medieval world, altered the groups that exercised it, and reshaped the role of the state in the economy. These changes stemmed from the advent of the printing press, the triangular sail, and gunpowder.

The first systemic transformation of medieval Europe resulted from the invention of the printing press and the subsequent dissemination and interpretation of knowledge, which led to significant changes in conventional ideological power. Prior to this, the handwritten word in Latin was poorly distributed, with 99% of the population illiterate. The Church, particularly the Pope, held the monopoly on knowledge and interpretation of the Bible, imposing sanctions for deviations from its teachings. The advent of the printing press undermined the Church's monopoly on knowledge, beliefs, and ideas. This technological innovation gradually eroded the Church's dominant role as the sole authority on ideological, persuasive, and informational power, paving the way for the Reformation.

However, as with many technologies, the impact of the printing press varied according to the different social contexts. Initially, the Catholic Church saw the printing press as a means to augment its power. Not only was the Bible printed, but also a large quantity of indulgences were also printed, which the Church used to generate funds, thereby

increasing its ideological and economic influence. It was only a few decades later that the printing press became a tool for challenging the Church's authority. For instance, on October 31, 1517, Martin Luther used the printing press to disseminate his 95 Theses against the Catholic Church's sale of indulgences, marking a pivotal moment in the Reformation and highlighting the technology's role in undermining established power structures. This marks the beginning of the Reformation, as Luther's theses were immediately printed in thousands of copies using the Gutenberg press, which had initially been used to print indulgences. It became evident that this technology could be employed to achieve competing or opposing goals. Unlike most of his contemporaries, Luther was well-acquainted with the technology of printing and the printing business. He translated the Bible from Latin into German, enabling it to be printed in thousands of copies and making it accessible to every household, allowing individuals to read and interpret it themselves. This led to the emergence of Protestantism, which asserted that every believer had the capacity to read and interpret the Bible, challenging the previous model where the Pope held exclusive interpretative authority (Mark, 2022). This had ideological, power-related, and economic implications. The increased production of printed materials led to a higher demand for paper, printing presses, and distribution networks, spawning a new economic sector. The impact of this technological innovation mobilized millions of people and introduced the use of what would become known as "propaganda." A century later, it contributed to the Thirty Years' War in Europe, which resulted in approximately ten million deaths but radically reshaped the power dynamics of the continent, laying the foundations for modern nation-states. This technological breakthrough had systemic implications for the redistribution of power functions across Europe, altering its geopolitical and geoeconomic structure. The center of capitalist development shifted from the Catholic city-republics of northern Italy to Protestant Holland and northwestern Europe. Protestantism emerged as the religion of the bourgeoisie, rejecting Catholicism as a legitimizing force for the feudal era and imposing a Protestant ethic characterized by rejection of religious hierarchies and authority, moderation in consumption, and a focus on industriousness.

The second change pertains to compensatory power, also known as rewarding or economic power. The invention of the triangular sail and the development of more robust ships for long-distance voyages facilitated the rise of a new economic class: the early merchant bourgeoisie. This group amassed wealth through long-distance trade and the acquisition of luxury goods, shifting economic power from the traditional landowners – feudal lords – to this new emerging social class.

The third change concerns coercive power. The advent of gunpowder and the creation of early cannons and muskets allowed the centralization of coercive power, which had previously been dispersed among various feudal lords. This concentration of military power enabled the rise of absolute monarchies, which centralized control and, through their economic policies, also fostered the growth of the commercial bourgeoisie and large-scale manufactures (Kostiner, 2024).

The First Technological Revolution also fundamentally reshaped power relations by concentrating power in the hands of industrial capitalists. The advancement of technologies

for the production of newspapers, the growth of urban populations, and the rise of an educated middle class – all necessary for the success of this revolution – led to the emergence of a secular intelligentsia. This period saw the formation of a national public sphere, the homogenization of population, the rise of nations, and new forms of ideological power tied to national identity. The industrial bourgeoisie did not require absolute monarchy but freedom of trade and sovereignty over its territory, realized through the nation-state and policies based on classical political economy. The country that first embraced this revolution gained competitive advantages in the production and distribution of goods and incorporated new communication technologies to project its soft power, ideology, and culture globally. As a result Great Britain emerged as a leading global power (Ward, 1994).

The Second Technological Revolution significantly strengthened the role of the nation-state, concentrating power within its hands through the centralizing capabilities provided by Fordist technologies, which included mass production, mass communications, mass armies, and weapons of mass destruction. Politics began to influence, plan, and direct economic processes. Liberal representative democracy, for instance, became viable only with the advent of mass communication technologies that enabled the creation of a vast public sphere. During this period, technology dramatically enhanced the capabilities of politics and the state. This was evident in the formation of powerful socialist states in the East and welfare states in the West, both of which emerged as a direct result of the technological advancements of the Second Technological Revolution.

The Third Technological Revolution is characterized by technologies that enable the demassification of the production of goods, services, and information, leading to a decline in the mass political parties and fragmentation of power among multiple entities. This revolution facilitates the globalization of capital, the rapid expansion of transnational corporations, and a shift away from welfare state economies. It also amplifies the production of ideas, culture, and information, enhancing the role of cultural industries. These industries allow states to exert influence through the so-called "soft power." The United States were the country that first adopted these technologies, which helped them to successfully create a globalized American public sphere and supported the delegitimization of Soviet-type socialist regimes, which had previously relied on technologies from the Second Technological Revolution.

The Fourth Technological Revolution is defined by advancements in artificial intelligence, big data, and the integration of technological, physical, and biological systems. This revolution results in increasingly complex interactions and connections, heightening various risks, dangers, and crises. It sparks battles for digital sovereignty, technological and economic conflicts, and contributes to global destabilization. The trend is towards using “big data” and algorithms as a tool for control and management of the growing number of crises, which threatens to become a new form of control over the individuals (Boersma et al., 2017) and creates new dangers to the sovereignty of the states. These developments lead to deglobalization trends, efforts of de-offshorisation, and strengthened state control over economic and social life.

3.2. Systemic consequences for society

The emergence and development of the modern state and its economic regulation are fundamentally tied to technologies such as the printing press. This invention enabled the widespread dissemination of printed books and newspapers, which became crucial for the homogenization of population within a territory, fostering a national identity and a unified national language. The printing press allowed people to connect by reading the same texts, overcoming local dialect differences and creating a shared official language. Consequently, local identities evolved into national identities. The First Technological Revolution significantly advanced this process. For instance, the Bulgarian Revival of the 19th century, which occurred several centuries after similar movements in Western Europe, can be understood through this lens. During the Ottoman Empire, Sultan Selim I issued a decree in 1515 that imposed the death penalty for using the printing press (Jafar, 2015), and even in the second half of the 18th century Paisius's "History of the Slav-Bulgarian People" was initially written, copied, and distributed by hand. The subsequent rise in printed books and newspapers in Bulgarian ultimately facilitated the Revival movement in Bulgaria.

During the Second Technological Revolution, advancements in mass communication technologies enabled intensive and centralized influence over mass consciousness and behavior. These technologies facilitated the emergence of super-national identities, which in turn strengthened the role of the state by homogenizing populations around a common language, shared heritage, and collective memory. This technological shift was a key factor, alongside geopolitical influences, in the disintegration of large multinational empires such as the Austro-Hungarian, Ottoman, and Russian empires. The mass communication technologies of this era played a crucial role in developing powerful political, propaganda, and ideological apparatuses that unified populations and legitimized state policies.

Technological revolutions serve both as a catalyst for the formation of national communities and a factor in their disintegration. The Third Technological Revolution, which weakens the cohesion of nation-states and national loyalties, significantly contributes to the fragmentation of existing national communities. This has led to separatist movements and the collapse of entities like the USSR and Yugoslavia, as well as to ethnic revivals in regions such as Wallonia in Belgium, Catalonia in Spain, and elsewhere. The Third Technological Revolution facilitates instantaneous communication across the globe, giving rise to what is referred to as "remote" and "digital nationalism." This phenomenon is particularly evident among immigrant communities, which can’t integrate into local national majorities. Notably, immigrant diasporas can exhibit stronger nationalist sentiments than those residing in their countries of origin. For example, a Polish person in Chicago may demonstrate greater nationalism than a Polish person in Warsaw, and the Turks in Germany are more likely to support Erdogan's pro-islamist party than the Turks in Turkey. Digital nationalism, which preserves and amplifies the identities of immigrant communities with the help of the global information and communication technologies, plays a significant, though not sole, role in the challenges faced by multiculturalism in the West and the difficulties in the integration of immigrants (Conversi, 2012).

The Fourth Technological Revolution further intensifies these processes through mobile communications and the move of a significant part of the population into the digital realm. This transition occurs at minimal costs and increasingly affects various activities, diminishing the constraints of physical space. Mobile communications have become a powerful force in social and economic interactions. Smartphones, now the most widely purchased high-tech products, are revolutionizing how news, information, entertainment, advertising, marketing, electronic services, conferencing, consulting, remote work, commerce, and finance are accessed and consumed. The previous boundaries of collective identities within nation-states further eroded as linguistic and cultural communities became defined less by physical and more by virtual spaces, where real distances lose their significance. In place of the mass culture of the Second technological, a mass of parallel cultures emerged. This shift, combined with the socio-economic divisions, disparities in soft power, and ideological influences between regions and countries, sparks battles over identity, and leads to rapid reinterpretations of historical narratives, transformations in the perception of the present, and swift changes in identities within states, affecting their unity or disunity within existing borders.

Subsequent technological revolutions change the culture and morals within which the producers and consumers of various goods function, and this has a reverse effect on states. If culture is considered as a supra-biological form of communication of individuals, then the technological forms of this communication lead to changes in it. The ways of formation and integration of different cultural communities and identities are transformed. Man and society of the "Gutenberg galaxy", where print culture dominates, are different from the ones in the world of radio, cinema, television with their various forms of image culture, and different yet again in the age of the Fourth Technological Revolution, when virtual and augmented reality, the creation with the help of algorithms of all kinds of images of non-existent people in any situation, the creation of a gigantic amount of so-called memes – various images, video products, texts that can be processed digitally and spread quickly on the Internet. Culture itself becomes an important element of the economy, as its share in economic activity increases due to the increased scale of its consumption. During the Third Technological Revolution, culture increasingly becomes commodified, transforming into an element of market exchange. As a result, its educational value diminishes while its entertainment function expands. Every cultural product is reduced to a marketable commodity. It is no coincidence that the United States observes the highest number of reports of UFOs, poltergeists, and other supernatural powers (Cornish, 2018). Such stories are easily commercialized, providing lucrative opportunities for profit.

The First Technological Revolution laid the groundwork for the emergence of what is known as modern society and modernity, characterized by secularization and an increasing belief in science and knowledge. People began to fight and sacrifice for a non-religious future and for life within their nation-states. The Second Technological Revolution further accelerated this shift, notably due to its

centralizing effects. This period saw the rise of intellectuals, who were increasingly regarded as authorities on scientific and social truths crucial to the masses. The Third Technological Revolution is associated with postmodernity and post-secularization, introducing global realities where people are motivated by post-secular or religious values. Its decentralized nature contributed to the weakening and marginalization of the previously dominant intellectuals. The Fourth Technological Revolution introduces the concept of "hyper-connectivity," where everything is directly and almost immediately interdependent. This profound interconnection makes the systemic consequences of technological changes faster, more comprehensive, and more unpredictable than ever before.

3.3. The systemic consequences for the economy

Technological revolutions are both a consequence of and a response to economic dynamics, often stemming from adverse economic conditions. The primary driver behind technological development and revolutions is the declining rate of profit. When traditional forms of economic regulation or the pursuit of comparative advantages are no longer sufficient to sustain profitability or competitiveness, innovations become crucial. These innovations typically involve new technologies and organizational forms. Technological revolutions generally follow periods of severe economic crises, during which existing ideas are expanded and new technological changes emerge. To fully understand how the nature of technological development influences the economic system, two particularly important points should be considered.

3.3.1. Different types of technologies can dominantly impact separate subsystems of the economy as well as the social system as a whole

There are four types of technology that transform production, distribution, exchange, and consumption, thereby reshaping the relationships people form in these processes and, as a result, the entire social system.

Production technologies involve various types of machinery and act directly as a means of labor, which is directly related to the manufacturing of goods. In addition, these technologies influence the nature of property and the distribution of labor's output.

Transport technologies are essential in determining the manner, extent, and cost of exchanging goods and services, as well as for the mobility of labor. The introduction of the steamship and the railway during the First Technological Revolution greatly increased the volume of manufactured goods and heightened international competition. Britain gained an advantage through its ability to produce industrial goods with machines at substantially lower costs. The Third Technological Revolution further advanced this by enhancing the ability of goods from around the world to compete in various markets. This competition can be regulated or mitigated primarily through tariff and non-tariff barriers.

Communication technologies are crucial for power relations, as they create new opportunities for existing power structures to influence mass consciousness and behavior. They also underpin the development of advertising, marketing, and branding, thereby affecting the nature and extent of exchange and consumption. Even in their early stages, these technologies played a significant role

in the financial sphere. During the First Technological Revolution the transatlantic submarine telegraph cable between Great Britain and the USA (1858) was pivotal for the internationalization and financialization of economies in the late 19th century. The Third Technological Revolution further transformed information and communication technologies, enabling cheap and rapid global communication. This reduction in transaction costs to nearly zero facilitated the movement of finance capital beyond state control, leading to a global economy where most of the financial flows are disconnected from the real economy of production and exchange of material goods and services. This environment allowed Southeast Asian economies, especially China, to leverage their lower labor costs for global competitiveness in labor-intensive industries. The Fourth Technological Revolution introduces new technologies in production, such as robotics and 3D printing, which begins to erode this competitive advantage by shifting the focus to skilled labor. New tools are developed to attract skilled workers from the less developed countries. Additionally, virtual platforms facilitate direct connections between consumers and producers, further reducing transportation costs and enhancing global trade dynamics.

Energy technologies are crucial to production and transportation, facilitating exchange and significantly increasing the movement of people and goods across the globe. During the First Technological Revolution, the steam engine, invented by James Watt in 1774, was quickly implemented in both manufacturing and rail and sea transport. In the Second Technological Revolution, the internal combustion engine revolutionized mass transport, leading to the construction of road infrastructure, as well as wars and conflicts over energy sources like oil. Lenin famously envisioned a socialist society as “Soviet power plus electrification”. Now, in the midst of the Fourth Technological Revolution and faced with environmental challenges, the importance of “green technologies” is growing rapidly. Self-driving vehicles, electric cars, and drones are expected to reduce hydrocarbon emissions while simultaneously threatening a significant number of jobs in transport and conventional energy production. What increasingly distinguishes the energy technologies of the First and Second Technological Revolutions from those of the Fourth is their reliance on different energy sources. While the former technologies are based on non-renewable resources such as oil, coal, and gas, the technologies of the current revolution depend on renewable sources like wind, sun, and hydro power. These renewable sources are both abundant and reliant on natural processes rather than human control, as humans cannot make the wind blow, the sun shine, or the rivers flow. It is widely believed that the adoption of renewable energy will drive decarbonization and help limit global warming. This belief has led to a global push for accelerating their implementation and the EU is setting an ambitious goal of achieving carbon neutrality by 2050. However, treating this goal as an end in itself can often lead to unintended consequences. These may include a loss of competitiveness due to energy shortages and rising electricity prices, deindustrialization, widespread impoverishment, and associated social unrest or political upheavals. Furthermore, the secondary effects of renewable technologies – such as deforestation, the reduction of agricultural land, disruptions to air currents,

threats to biodiversity, and challenges in recycling that result in soil and groundwater pollution – cannot be ignored. The necessity of such a green transition in Europe is also questioned, because the air is part of a planetary ecosystem that demands a global rather than a local approach. Moreover, if global warming is driven not by subjective human economic activities but by objective natural processes – such as those historically responsible for ice ages and warming periods – this raises significant questions about the assumptions underlying current energy policies.

3.3.2. Technology is not just an element of productive forces, but it directly or indirectly affects every social subsystem and the whole society

Technological revolutions fundamentally alter productive forces and, consequently, production relations. They primarily influence different types of property relations. The First Technological Revolution was facilitated by the dominance of private ownership, although the state played a crucial role in certain infrastructural domains. For example, the British state actively supported the development of railways and postal services. The Second Technological Revolution enhanced the management of collective property, reflected in the increased share of state property in capitalist countries and the rise of state socialism, where state ownership became predominant. The Third Technological Revolution, by contrast, set the stage for the privatization of state property. It also introduced new characteristics to the labor force, such as intellectual capital, human capital, and social capital, which differed from the previous emphasis on unskilled labor. This revolution contributed to blurring the traditional boundaries between labor and capital. The Fourth Technological Revolution further intensifies these changes, with knowledge, information, and data, which play a central role in the property sphere. Platforms and data become significant sources of profit. Additionally, new forms of collective ownership emerge, including open source, the sharing economy, and platform collectives.

Technological revolutions also transform distributional relations. During the First Technological Revolution, the relations between labor and capital owners became increasingly polarized and antagonistic. This period saw a clear divide between the industrial proletariat and the capitalists. However, technological advancements also increased the demand for skilled workers, leading to higher wages. Consequently, modern education systems began to develop, ranging from compulsory state-supported primary education to universities aimed at producing high-quality specialists. In the Second Technological Revolution, state intervention became more profound, resulting in significant income redistribution and the growth of qualified occupations with higher wages. This era saw the rise of the middle class in a society increasingly characterized as "consumer-oriented". The Third Technological Revolution saw a decrease in the proportion of labor in the production of new goods, accompanied by an increase in capital profits. This shift led to a new growth in income inequality. The Fourth Technological Revolution appears to intensify these inequalities, but it also creates opportunities for increased consumption by a larger portion of the population and further reduction in poverty. It may usher in a new phase of reduced working hours

and transformations in educational systems. Consequently, various countries are currently experimenting with policies such as universal basic income and four-day workweek.

Thus, the First Technological Revolution led to a rapid increase in industrial production, accompanied by a widening gap in wages and wealth during the era of "first globalization" or internationalization in the 19th century. This intensification of economic disparities prompted the introduction of the first social laws and social systems in countries like Great Britain and Germany during the late 19th century. The Second Technological Revolution supported the strengthening of the state through various mechanisms, such as Keynesian economic policies aimed at stimulating aggregate consumption, which contributed to the reduction of inequality and fostered the rise of the middle class. However, in less developed countries, increasing distributional inequalities exacerbated social tensions, which led to revolutions and to the establishment of Soviet-style socialism in Eastern Europe. The Third Technological Revolution facilitated the globalization of production, trade, finance, and labor. While this expansion increased global wealth, it also diminished the redistributive capabilities of the state, weakened trade unions, and exacerbated inequalities. These changes contributed to the growing dissatisfaction among significant segments of the population with politicians and their ability to address complex social contradictions. The Fourth Technological Revolution has further intensified these trends, leading to increased crises of liberal democracy and deglobalization trends. This period has also seen a resurgence of the nation-state's role and its redistributive functions, as evidenced by recent policies under the Biden and Trump administrations in the USA.

Technological revolutions also transform the relations of exchange. With advancements in communication and transport technologies, each stage of technological progress has progressively reduced exchange costs and facilitated the development of global value chains. During the First Technological Revolution, the market was the dominant force, while the Second Technological Revolution saw increased state regulation and a significant portion of exchange being managed within the state frameworks. The Third Technological Revolution set the stage for the globalization of market exchange and a corresponding weakening of state control. The financial sector's role expanded significantly, gaining central importance in exchange processes. The Fourth Technological Revolution is rapidly reducing transaction costs and minimizing the role of intermediaries in exchanges. It emphasizes the growing significance of platforms in the platform economy, where big data becomes more critical than traditional market signals (Mason, 2015).

Different technological revolutions create opportunities for profiting from various types of consumer products, radically altering consumption relations. These revolutions enable the development of diverse market categories, including elitist, mass, niche, and individualized markets, each with distinct consumption patterns and products. During the pre-industrial phase of capitalism, characterized by long-distance trade and mercantilist policies, consumption largely catered to the status needs of the aristocracy and the emerging bourgeoisie. This trend continued into the First Technological Revolution, which is reflected in Thorstein

Veblen's work "The Theory of the Leisure Class" (Veblen, 1899), where he analyzed ostentatious or status-driven consumption. The Second Technological Revolution introduced mass society, leading to mass production and consumption of goods, services, and information, which contributed to the rise of the middle class. The Third Technological Revolution furthered the trend towards demassification, giving rise to niche markets tailored to specific consumer groups. The Fourth Technological Revolution enables the individualized production of goods and services, making them both accessible and affordable. Each technological revolution also brings innovations into the consumer's home, transforming domestic life by changing work characteristics, increasing leisure time, and altering gender roles. These innovations – from basic necessities like food, medicine, and clothing, to household appliances and modern digital technologies – revolutionize living conditions, family dynamics, and the pace of life. The electrification of homes and the advent of water supply and heating systems dramatically improved domestic comfort. Subsequent technologies, such as electric stoves, radios, TVs, vacuum cleaners, and home robots, further enhanced domestic efficiency and altered family relationships. Each technological revolution thus creates new needs and opportunities to address them, continuously reshaping the hierarchy of individual needs and consumption patterns.

Technological revolutions drive significant changes in labor organization and the nature of economic entities by transforming production, exchange, distribution, and consumption processes. Each technological phase introduces different models of labor organization and shapes the emergence of different types of economic subjects. During the Second Technological Revolution, innovations such as the Fordist assembly line fostered the rise of large hierarchical corporate structures and extensive state ownership. This era also created the foundational prerequisites for Soviet-style socialism. The hierarchical management structures of Fordism were pivotal in organizing production on a grand scale. However, the Third Technological Revolution began to erode these Fordist structures. With advancements in communication technologies and global connectivity, production and management practices evolved towards a more decentralized and horizontally integrated model. For example, by the early 1980s, Mitsubishi's communication networks spanned approximately 450,000 kilometers, handling over 4.5 million words daily. Similarly, Texas Instruments, by the late 1980s, operated about 50 plants across nineteen countries, utilizing satellite communications to synchronize global production planning, costing, financial planning, marketing, customer service, and personnel management. Their system featured nearly 300 job acceptance terminals, around 8,000 survey terminals, and 140 networked computers (Dicken, 1992, p. 108). In the Fourth Technological Revolution, the advent of high-tech platforms and digital technologies has given rise to super-large technology companies. These companies, with their global operations and extensive data-driven platforms, now surpass many countries in terms of economic influence and scale.

The four technological revolutions differ in their roles in the division of labor, influencing production efficiency and cost reduction, thereby reshaping the organization of work. In the early stages of capitalism, particularly during the First and Second Technological

Revolutions, trends toward increasing specialization in labor were prominent, including in scientific knowledge, where the number of disciplines expanded. Since the Third Technological Revolution, there has been a strong trend toward integration, and the convergent effects of the Fourth Technological Revolution have further strengthened this process, resulting in a dominant trend of integration in scientific fields as well.

The nature of work and the fundamental dimensions of societal structure have also evolved, affecting production organization and the workforce. During the First Technological Revolution and before, physical labor was predominant. Over time, however, the demand for skilled labor in various production sectors increased, leading to higher wages and changes in the social structure. The Second Technological Revolution contributed to the rise of an income-defined middle class, a shift from earlier expectations that a property-defined working class would prevail. In the Third and Fourth Technological Revolutions, the emphasis has shifted to skills such as heuristics, innovation, creativity, continuous education, and retraining. Consequently, there has been a rise in start-up companies and innovation hubs where these skills are crucial. There are even concerns that with the development of artificial intelligence, the need for human labor may diminish, which could undermine two of the core pillars of capitalism – labor and the market. If labor is no longer needed, there would be no work force to sell for a wage, and thus no income to purchase goods and services available on the market. Therefore, the political economy of artificial intelligence implies the regulation of artificial intelligence and the optimization of systemic interdependencies between labor, the market, and the distribution of wealth (Kasy, 2023). Simultaneously, technologies have transformed work in all its dimensions, including domestic labor. Advances since the 19th century in technologies related to housing and domestic tasks (such as heating, cooking, cleaning tools, etc.) have significantly reduced the amount and nature of domestic work for women, which has been a key factor in their increased participation in the workforce across all sectors of society.

Furthermore, each technological revolution introduces innovations that alter the nature, role, and dynamics of the primary factors of production: land, labor, and capital. At each stage of a technological revolution, the role of land evolves significantly. Initially, land was used for the direct production and consumption of plant and animal products. With the advent of the First Technological Revolution, land became crucial as a source of resources like coal. In the Second Technological Revolution, oil, gas, and various metals took precedence. By the Fourth Technological Revolution, the focus has shifted towards principles of the circular economy, emphasizing sustainability and resource efficiency. Labor also undergoes transformation across technological revolutions. It begins with simple physical labor during the pre-industrial period and the First Technological Revolution, evolves through various forms of labor in the Second and Third Technological Revolutions, and advances to highly specialized and skilled labor associated with technologies of the Fourth Technological Revolution. The types of capital that also change over time. The focus shifts from commercial capital in earlier periods to industrial and financial capital during subsequent revolutions. In the Fourth Technological Revolution, human, symbolic, and intellectual capital gained prominence,

reflecting their increasing importance in the modern economy.

The movement of various factors of production has evolved significantly across technological revolutions. Initially, in the pre-industrial era, the movement of goods was constrained by the limitations of land and transport, facilitating the mercantilist stage where rare and exotic goods, including new species of plants and animals, were traded between regions. With the First Technological Revolution, advancements in transport technology, such as the development of railways, dramatically reduced transportation costs. This paved the way for global value chains and contributed to the globalization of production. Subsequent technological revolutions continued to advance transport capabilities with the advent of large trucks and container ships, further accelerating global trade. The movement of capital, particularly financial capital, also evolved. The rise of financial capital, a key element in theories of imperialism, was significantly facilitated by the advent of the telegraph in the 19th century, which connected global stock markets. From the 1980s onwards, the introduction of computing technologies, including personal computers and spreadsheets, revolutionized financial operations. The Third Technological Revolution enabled rapid decision-making, futures trading, and instantaneous transactions across global stock markets. The acceleration in the movement of financial capital was a crucial factor in the globalization and financialization of economies. The Fourth Technological Revolution introduces new forms of capital, such as human, intellectual, symbolic, and social capital. Data ownership has emerged as a dominant form of capital, with major technology companies deriving significant profits from the data of billions of users. This shift underscores the importance of data in the modern economy and highlights the evolving nature of capital in the digital age.

Conclusion

Each technological revolution brings radical changes to the entire economic system, including the production, distribution, exchange, and consumption of goods, as well as shifts in property relations, labor dynamics, and the organization of production. These revolutions also transform political systems, state policies, and the world system, influencing and being influenced by political economy thinking. Technological revolutions introduce new methods of production that, in turn, reshape political economy. These shifts impact property relations, distribution, exchange, and consumption, while also affecting culture and politics. Technologies can directly alter production processes, energy security, or communications, thereby influencing political systems, state functions, public relations, and the economy. Conversely, political, economic, and social conditions influence technological development. Thus, technologies, economics, and politics are interconnected through direct and feedback links, greatly amplifying the scale of their interaction. This dynamic causes emergent consequences, modifies existing systems, and introduces new elements related to various functional dependencies. As a result, each subsequent technological revolution leads to changes in economics, politics, and societies, affecting both national and global political-economic systems. These changes alter the relationships between the state and the market, politics and the economy, capital and labor, as well as the center, periphery, and semi-periphery of the world system.

In recent decades, the exponential growth, convergence, and disruptive nature of new technologies have complicated social systems. This complexity has given rise to theories about complex systems, chaos theory, global risk society, and digital risk society, all of which are trying to understand the ongoing crises across various sub-systems and in society as a whole. Efforts to address these crises increasingly rely on advanced technologies such as rapid data collection and processing, the Internet of Things, digital twins, artificial intelligence, and quantum computing. These technologies, which have rapidly developed during the Fourth Technological Revolution, are seen as essential tools for navigating and mitigating the challenges of the contemporary world.

This complex system of interactions prompted the effort to develop a comprehensive theoretical framework that may elucidate the logic of systemic interactions and facilitate the analysis of various technological revolutions. This is especially crucial in the understanding of the Fourth Technological Revolution, its controversies, and its risks. The proposed framework was based on examining the systemic interrelationships among three fundamental societal subsystems: technology, economics, and politics. To achieve this, a political economy approach was employed, focusing on the systemic interactions among these subsystems to provide a broader view of changes within the overall political economy system. This approach represents a significant contribution, as existing research often isolates aspects of technological revolutions, offering fragmented insights. In contrast, this framework aims to provide a holistic perspective, acknowledging that not only does the whole system influence its parts, but each part also affects the whole. The politico-economic system itself is formed by the interrelation between technology, economics, and politics. Consequently, to grasp the implications of the Fourth Technological Revolution, it is essential to view it as part of a cohesive system. This approach mirrors the methodology of classical political economists of the 19th century, who formulated comprehensive economic theories by deriving specific insights from general principles. Their systematic approach laid the foundation for understanding the political economy, and this method remains relevant for analyzing contemporary technological and economic transformations.

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