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The formation logic of new quality productive forces in the construction of China's independent economic knowledge system

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Abstract

Purpose – The paper aims to show how the construction of an independent knowledge system is a process of transforming practical experience into systematic knowledge, with a terminological revolution at its core.

Design/methodology/approach – This paper shows that to harness the role of new quality productive forces (NQPFs) in advancing the Chinese path to modernization and high-quality development, it is essential to apply the Marxist political economy's methodology of integrating theory with historical analysis. This approach enables a systematic, theoretical explication of the formative logic behind NQPFs within the framework of China's independent economic knowledge system. This requires adherence to historical materialism as both a theoretical foundation and methodological approach for understanding the developmental rationale of NQPFs in the construction of China's independent economic knowledge system.

Findings – From a national perspective, NQPFs embody the most recent achievement in the evolution of advanced productive forces throughout the developmental practice of the People's Republic of China (PRC). Theoretically, the formation of NQPFs results from the internal contradictory dynamics inherent in productive forces. Their development follows the "science and technology-industry-productive forces" paradigm, whereby emerging technologies are integrated into new industries, generating new factors reliant on these technological advances, and thereby driving a qualitative transformation and leap in the structural composition of productive forces.

Originality/value – The theory of NQPFs represents a profound extension of Xi Jinping's thought on economy and a highly original contribution to the construction of China's independent economic knowledge system. It significantly develops the Marxist theory of productive forces, opening new horizons for the development of China's independent economic knowledge system. This theory also provides answers to China-specific inquiries, global challenges, people-centered concerns and epochal questions in the process of building China's independent economic knowledge system.

Keywords Independent knowledge system, New quality productive forces, Productive force theory, Terminological revolution, Iconic concepts

Paper type Translated paper

An independent knowledge system in economics constitutes an integrated framework comprising logically interconnected concepts, principles and methodologies. It encompasses the disciplinary framework, academic system and discursive system of economics. The development of China's independent economic knowledge system is a process of theorizing the empirical experience of China's economic development. Within the establishment of the three major systems, concepts and academic terminology serve as the bedrock. As Jian (2023) notes, "The academic system forms the basis of both the disciplinary and discursive systems; the key to establishing the 'three

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systems' lies in formulating systematic, comprehensive, accurate, and scientifically grounded concepts and theoretical propositions". The theory of new quality productive forces (NQPFs) represents a profound extension of Xi Jinping's thought on economy and a highly original contribution to the construction of China's independent economic knowledge system. It significantly develops the Marxist theory of productive forces, opening new horizons for the development of China's independent economic knowledge system. This theory also provides answers to China-specific inquiries, global challenges, people-centered concerns and epochal questions in the process of building China's independent economic knowledge system. To harness the role of NQPFs in advancing Chinese path to modernization and high-quality development, it is essential to apply the Marxist political economy's methodology of integrating theory with historical analysis. This approach enables a systematic, theoretical explication of the formative logic behind NQPFs within the framework of China's independent economic knowledge system. This requires adherence to historical materialism as both a theoretical foundation and methodological approach for understanding the developmental rationale of NQPFs in the construction of China's independent economic knowledge system.

1. NQPFs driving the construction of China's independent economic knowledge system

1.1 NQPFs as a terminological revolution in the construction of China's independent economic knowledge system

Terminology serves as a foundational cornerstone for scientific theoretical innovation. A "terminological revolution" is an intrinsic requirement for achieving theoretical breakthroughs. In the development of social sciences, such a revolution involves the replacement of outdated terminology with new terms, often manifesting as the reinterpretation of existing concepts and the creation of novel ideas. Terminological revolutions thus reflect the innovation and evolution of knowledge in the social sciences. As Engels (2009a, p. 32) noted when discussing the theoretical innovation and scientific spirit of *Das Kapital*, "Every new aspect of a science involves a revolution in the technical terms of that science". The emergence of the concept of NQPFs has expanded the conceptual framework of Chinese economic discourse, enhancing the originality and competitiveness of China's independent economic knowledge system. This paradigm elevates its pioneering and leadership potential while expanding its global discursive influence.

On the one hand, the theory of NQPFs deepens and refines the Marxist political economy's interpretation of the general laws of social development. It addresses the long-standing gaps in traditional political economy concerning the study of productive forces and makes a pioneering contribution. The theory elucidates the qualitative leap in productive forces within the current wave of scientific and technological revolution and industrial transformation. It systematically explains how such qualitative transformations propel socioeconomic progress, thereby elevating the Marxist logic of liberating, developing and protecting productive forces to the level of transformative change in the qualitative state of productive forces itself. This injects new vitality into Marxist political economy and reveals emerging patterns in the development of productive forces under socialism with Chinese characteristics for a new era. On the other hand, NQPFs constitute a practical entry point and a central proposition of Xi Jinping's thought on economy. They extend this body of thought from a focus on relations of production to an emphasis on productive forces, advancing from the triad of liberation, development, and protection of productive forces to the notion of a qualitative revolution. From the perspective of techno-economic paradigms, NQPFs incorporate new factors of production into the input system, establish novel modes of production and position innovation incentives as a key driver of development within the broader social institutional framework.

1.2 NQPFs as an iconic concept in the construction of China's independent economic knowledge system

An independent knowledge system refers to the body of knowledge distilled and synthesized from a nation's practical experiences during a specific historical period. The construction of such a

system is a process of transforming empirical practices into structured knowledge, with its core being the formation of iconic concepts through a revolution in terminology. These iconic concepts embody theoretical subjectivity and discursive autonomy within an independent knowledge system. They not only demonstrate theoretical originality but also manifest the system's theoretical subjectivity and its significance within global scholarly discourse. As Xi (2023, p. 486) articulated, "We must excel at refining iconic concepts by developing new concepts, categories, and formulations that are accessible and comprehensible to the international community". In the process of building an independent knowledge system, such iconic concepts play a pivotal role. Rooted in local contexts and value systems, they serve as central elements that endow a knowledge system with a unique identity and discursive autonomy. The concept of NQPFs is grounded in the practical experience of socialist economic development since the advent of the new era in China. It is an original theoretical proposition that exhibits the characteristics of an iconic concept: demonstrating both theoretical subjectivity and intellectual originality. Over the seven decades since the founding of the PRC, the Communist Party of China's conceptualization on productive forces has undergone a significant historical evolution – from an emphasis on developing productive forces in the early years, to the reform-era paradigm of liberating and developing productive forces, culminating in Xi's formulation that integrates liberating, developing and protecting productive forces as an organic triad in the new era (Ren, 2018).

In the new phase of China's development, the pursuit of high-quality growth and Chinese modernization has put forward new requirements for the development of productive forces. Against the backdrop of a new global scientific and technological revolution, Xi's formulation of the theory of NQPFs represents an innovative extension of the Marxist theory of productive forces. It endows the latter with contemporary relevance while serving as a newly refined iconic concept in the construction of China's independent economic knowledge system. In the era of the digital economy, NQPFs have attained new historical significance by establishing themselves as an iconic concept through terminological innovation in productive forces. Underpinned by digital technologies, NQPFs restructure the core factors of production around technological and data elements, elevating scientific and technological innovation as the primary productive force while positioning data as a new catalytic element for optimizing the factor structure. This systemic upgrade of productive forces empowers a qualitative transformation, serving as the driving force behind the formation of NQPFs. Thus, as an iconic concept, NQPFs embody the universal laws and common features of the modernization of global productive forces, while also bearing distinctive traits rooted in China's national conditions, thereby reflecting China's innovative path toward high-quality economic development driven by qualitative transformations in productive forces.

1.3 NQPFs as a pioneering force in the construction of China's independent economic knowledge system

From a theoretical perspective, at a new historical juncture, NQPFs represent a significant advancement of Marx's theory of productive forces, enriching Marxist theory with contemporary relevance and pioneering new frontiers in developing China's independent economic knowledge system. The theory of NQPFs, grounded in the context of the new global scientific and industrial revolutions, seizes the historical opportunities of the "great changes unseen in a century". It reveals the inherent laws governing the dynamics of productive forces under socialism with Chinese characteristics. Guided by these laws, the theory not only provides fundamental direction for the evolution of socialist relations of production with Chinese characteristics but also opens new pathways for achieving high-quality development and Chinese modernization, standing as a model for the construction of China's independent economic knowledge system.

First, it advances Marxist theory on the composition of productive forces in the context of a new round of technological revolution. While remaining grounded in Marxist principles, the theory of NQPFs emphasizes the central role of science and technology, conceptualizing

productive forces as a composite structure formed through the close integration of laborers, means of labor, and objects of labor. This represents an extension of Marxist theories on the composition of productive forces in the context of the new technological revolution. Second, it builds on Marx's theory of the combination of productive forces in light of the new industrial revolution. NQPFs emphasize the optimization and integration of resources for technological innovation. In essence, they stress combined productive forces, highlighting the systemic coherence and structural rationality of the productive forces system. Third, it promotes the modernization of the Marxist theory of productive forces by following the general laws governing the development of productive forces. Within the logical framework of Marxist political economy, productive forces also possess characteristics of modernization. NQPFs represent the latest advancement in the modernization of productive forces, embodying a qualitative leap in the development level of productive forces and significantly expanding their development space.

2. The historical logic behind the formation of NQPFs in the construction of China's independent economic knowledge system

The construction of China's independent economic knowledge system entails the intellectualization and theorization of practical experience and must be grounded in a historical perspective. As Xi (2016, p. 3) emphasized, "To understand contemporary Chinese philosophy and social sciences, one must adopt a broad perspective and situate them within the larger historical context of both global and China's development". In studying the formation logic of NQPFs within the construction of an independent knowledge system, one must first examine the historical logic of their formation, because the construction of China's independent knowledge system of economics cannot be separated from its historical foundation. As Engels (2009b, p. 603) observed, "The point where this history begins must also be the starting point of the train of thought, and its further progress will be simply the reflection, in abstract and theoretically consistent form, of the historical course". From the perspective of historical logic, NQPFs encompass two historical perspectives: the global and the national, both of which reflect the transformation from traditional productive forces to NQPFs.

2.1 The global historical perspective on the formation of NQPFs

China's independent economic knowledge system forms an integral part of the global knowledge system. To investigate the historical logic underlying the formation of NQPFs, it is necessary to situate them within the broader trajectory of world history and adopt a global historical viewpoint. From this perspective, major leaps in human productive forces can be traced back to the Industrial Revolution, during which the scientific and technological revolution significantly enhanced industrial labor productivity. The development of modern industry was largely driven by the advance of productive forces, with scientific and technological progress serving as the decisive factor in improving labor productivity. Scientific and technological revolutions laid the material foundation for the expanded reproduction of the industrial sector. Mainstream scholarship generally holds that human society has undergone four major technological revolutions since the Industrial Revolution.

The first technological revolution engendered the First Industrial Revolution (IR1.0), during which large-scale machine production became the dominant mode of industrial production. The productive forces generated by the IR1.0 gave rise to emerging industries such as textiles and coal, while the invention and widespread application of industrial machinery further spurred technological innovation in heavy industry and transportation. As a result, social productive forces developed with unprecedented speed, fundamentally transforming the structure of society. The second technological revolution took shape in the 1870s, marked by the introduction of new steelmaking methods and the widespread application of electricity. During this technological revolution, vast quantities of primary energy sources such as coal and petroleum were converted

into electrical energy, which is easier to utilize and transmit. This transformation significantly advanced social productive forces and transformed human lifestyles. By the early 1890s, electricity had become widely applied in industrial production, driving rapid growth in industries such as electrical power, chemicals, petroleum and automobiles. At the same time, advancements in transportation and communication technologies have greatly facilitated global economic connectivity, driving unprecedented growth in productive forces.

Following Second World War, the third technological revolution emerged, marked by advancements in automation technology, electronic computers and the nuclear industry. This revolution fundamentally transformed nearly all major fields of science and technology. Emerging industries, including nuclear energy, electronics, semiconductors and aerospace, rapidly expanded, driving social productive forces to new heights. In particular, computer technology developed at a remarkable pace, undergoing continual iterations across four generations of component technologies and advancing toward a fifth. Current scholarly discussions of the "Fourth Industrial Revolution (IR4)", the "new industrial revolution", and the "digital economy" all stem from the progress of computer and automation technologies, reflecting both a leap in social productive forces and an improvement in management capabilities. From a global historical perspective of NQPFs, the development of human productive forces represents a dialectical unity featuring both inheritance and continuity, as well as stage-based progression. NQPFs are the concrete embodiment of the modernization of productive forces at the new stage in the development of human productive forces.

2.2 The national-historical perspective on the formation of NQPFs

China's independent knowledge system refers to a framework of regular understanding derived from China's historical and practical experiences. As such, its national character constitutes the core feature of this system, which is deeply rooted in the practice of Chinese modernization. From a national-historical perspective, NQPFs represent the most recent achievement in the development of advanced productive forces through the evolving practices of the PRC. Studying the formation of NQPFs from this historical perspective carries significant importance. "Grounded in the Chinese context and viewed from the perspectives of history and values, they elucidate the unique significance of a dynamic duality in the new era: the vibrant creativity of Chinese modernization under the guidance of historical materialism, and the enrichment and development of historical materialism in the 21st century through the practice of Chinese modernization" (Fang, 2021). The evolution of China's productive forces over more than 70 years since the founding of the People's Republic of China has been reflected mainly in three aspects: first, changes in the stage-specific characteristics of productive forces; second, changes in the factor endowments of productive forces; and third, changes in the technological conditions of productive forces.

In terms of shifts in the stage-specific characteristics, the development of productive forces has exhibited distinct phased features – from driving the transformation of China from an agricultural to an industrial nation through enhancing productive forces, to liberating and developing productive forces to promote reform and opening-up, then to liberating, developing and protecting productive forces to advance the building of a moderately prosperous society in all respects and finally to developing NQPFs to propel Chinese modernization and high-quality economic development. Regarding changes in factor endowment, China's labor force has undergone a shift from the release of demographic dividends to their gradual diminishment. Meanwhile, the endowment of natural resources has transitioned from a model driven by resource-based factors for economic growth to one propelled by technological innovation. In terms of changes in the technological conditions of productive forces, during the early years after the founding of the PRC, the technological conditions for productive forces were weak in China. Following China's reform and opening-up, the large-scale introduction of advanced foreign machinery significantly drove technological progress in China at that time, leading to the liberation of productive forces.

In 2012, the 18th National Congress of the Communist Party of China (CPC) proposed the innovation-driven development strategy, placing science and technology at the core of national development as a strategic support for social productive forces. With the advent of the IR4, artificial intelligence (AI) has developed rapidly and penetrated deeply into production, fundamentally reshaping the technological conditions and developmental trajectory of productive forces, thereby fostering the formation of NQPFs. Therefore, NQPFs represent the latest manifestation of the "qualitative transformation" of productive forces in the context of Chinese modernization, driven by changes in the phased characteristics of productive forces, factor endowments, and technological conditions.

2.3 NQPFs from the dual historical perspectives of globality and nationality

In constructing China's independent economic knowledge system, elucidating the historical logic behind the formation of NQPFs requires a careful balancing of global and national perspectives. From a historical viewpoint, the development of productive forces generally follows two paths: first, incremental quantitative growth, and second, transformative qualitative leaps. The latter can be characterized as a comprehensive transformation in both the structure and operation of productive forces (Kuczynski, 1975, p. 223). Such changes unfold with remarkable speed and scale, leading to profound transformations in both the modes of production and social relations across society. When viewed through the dual lenses of global and national historical contexts, NQPFs represent a revolutionary transformation – not merely changes in individual links or aspects, but a comprehensive restructuring of the overall system of productive force and its dynamic operations. This marks a revolution in the qualitative state of productive forces in the context of the new technological and industrial revolution.

Driven by the latest technological breakthroughs, NQPFs exhibit revolutionary characteristics in four key aspects. The first is the revolution in productive factors. While land, labor, capital, entrepreneurial skill and technology remain typical productive factors, the emergence of data as a new factor, coupled with the model of "data + computing power + algorithms", has created a new paradigm for understanding, utilizing and shaping the world. This empowers a structural upgrade of production factors, leading to a systemic revolution of these factors. The second is the revolution in labor. Within the framework of NQPFs built on "data + computing power + algorithms", workers are transitioning from manual or mental laborers into knowledge creators, thereby shaping a new type of labor subject and giving rise to a revolution in the labor force. The third is the revolution in tools. The NQPFs, driven by "data + computing power + algorithms", also trigger a revolution in tools, transforming productive instruments from manual tools and energy-conversion tools into intelligent tools. Through the use of these intelligent tools, laborers engage in the production of both material and intellectual products. The fourth is the revolution in the "techno-economic paradigm". In the traditional model, science, technology and production were relatively separate, with extended time lags required for scientific discoveries to evolve into applicable technologies and, subsequently, into mass production. However, in the new technological revolution, the "techno-economic paradigm" of productive forces has undergone a shift: science and technology are now more closely integrated, forming an organic whole and creating a unified system of "science–technology–production". This significantly shortens the cycle from science to production and brings about an overall qualitative change in social productive forces. Under these new conditions, the "techno-economic paradigm" of NQPFs has further evolved into a new model of "technology-industry-productive forces".

3. The theoretical logic behind the formation of NQPFs in the construction of China's independent economic knowledge system

The construction of China's independent economic knowledge system involves not only the systematization of practical experience into knowledge but also its theoretical elaboration,

thereby deepening the interpretation of significant practices, key experiences, and innovative theories. As Xi (2023, p. 484) has pointed out, "China's philosophy and social sciences should focus on the tasks we are currently undertaking, unearth new materials, identify new issues, propose new viewpoints, and construct new theories from the practice of China's reform and development. They should strengthen the systematic summarization of the practical experiences of reform, opening-up, and socialist modernization, enhance analytical research on developing the socialist market economy, democratic politics, advanced culture, harmonious society, ecological civilization, and the Party's governance capacity, and deepen the study and interpretation of the new concepts, ideas, and strategies of the Central Committee of the CPC in governing the country. This will help refine theoretically innovative theories and generalize regularities from new practices". Therefore, explaining the formation of NQPFs within the construction of China's independent economic knowledge system requires elucidating its theoretical logic on the basis of historical logic.

From a theoretical perspective, productive forces constitute a systemic power formed through the interaction of various factors. Among the many factors that shape productive forces, science and technology serve as the determining factor; education and management function as influencing factors, while laborers, means of labor and tools of labor constitute the material factors of productive forces (Ren, 2024). The formation of productive forces is essentially a process in which science and technology, as the determining factor, act upon material factors through influencing factors. Consequently, the development of productive forces does not follow a linear trajectory of growth. Instead, it is characterized by technological and industrial revolutions, perpetually undergoing a developmental process in which the "old quality" disintegrates and the "new quality" emerges. The formation of NQPFs adheres to the "science and technology–industry–productive forces" paradigm, which integrates new technologies into emerging industries, thereby generating new factors of production rooted in these advanced technologies. This process induces qualitative transformations and leaps in the structure of productive factors, leading to the formation of NQPFs. Against the backdrop of the current new round of technological revolution and industrial transformation, the integration of new technologies into new industries is primarily manifested in two aspects: First, the integration of tool-oriented new technologies related to energy dissipation into new industries, currently manifested in the digital economy driven by digital and intelligent technologies, namely, the formation of digital NQPFs. Second, the integration of power-oriented new technologies in energy supply into new industries, currently represented by the green economy and renewable energy technologies, i.e. the formation of green NQPFs.

3.1 The internal contradictory dynamics governing the formation of NQPFs

According to the principles of historical materialism, the general laws of the development of productive forces are primarily manifested in four aspects. First, breakthrough advancements in technological innovation and their industrialization represent the general pathway through which new productive forces are formed. As innovative technologies are continually embedded in the production process, they generate two distinct transformations in productive forces: incremental revolutions accelerate the formation and expansion of new industries; structural revolutions continuously improve traditional industries through new technologies, thereby forming a new industrial system. Second, the development of productive forces is a process of continuous evolution from lower-level to higher-level productive forces. With ongoing advancements in science and technology, continuous optimization of productive factors, and improvements in management, productive forces gradually evolve from simple to complex and from lower to higher stages, ultimately undergoing qualitative transformation. This process gradually replaces old productive forces and drives the overall progress of social productive forces. Third, the concentrated manifestation of the development of productive forces lies in the transformation of production methods. As productive forces advance, production methods also evolve from manual production to mechanization and

intelligentization. Fourth, once NQPFs take shape in specific regions, they continue to spread spatially, diffusing from developed to less developed areas, thereby persistently optimizing their spatial distribution.

In accordance with the general laws of the development of productive forces, NQPFs are essentially an advanced qualitative state of productive forces. The trajectory of "scientific invention–technological innovation–industrialization advancement" constitutes the fundamental pathway for the development of advanced productive forces (Chang, 2006). This suggests that the systems of tools of production, energy resources for production and internal contradictory dynamics within them are fundamentally determined by the level of technological innovation. The mode of technological innovation governs the intrinsically contradictory dynamics in the formation of NQPFs. As a late-developing modernizing country, China initially followed a technology catch-up model in the evolution of technological progress, encompassing technology selection, introduction, absorption and improvement. This combination of replicative and creative imitation generated a significant advantage in rapid economic growth. However, once the window of latecomer advantages narrows and constraints such as technological blockades by developed countries and resource-environmental pressures intensify, the catch-up model can no longer sustain such high-speed growth. A shift is thus required from technology catch-up to technology leadership, the key to which lies in extending the innovation chain toward the domain of knowledge creation. The non-rivalrous nature of knowledge renders possible a developmental pathway for advanced productive forces. The rise of digital technologies further amplifies this pathway through economies of scale, transitioning from "learning by doing" based on individual experience to "learning by doing" based on collective experience. This shift constitutes a critical technological premise for the leaps in productive forces and, ultimately, for the formation of NQPFs.

Within the context of the digital economy, networked and recombinative innovation models have emerged as the foundational logic for building China's technology leadership. Together with the traction of a super-large domestic market, breakthroughs facilitated by a new system for mobilizing the resources nationwide, collaborative innovation across industry–academia–research and catch-up along the entire industrial chain, these forces collectively constitute the system of Chinese style innovation in the new era. Under the synergistic effect of these innovation models, a technology leadership model has taken shape, characterized by "independent knowledge innovation–technological progress or invention–industrial innovation". The emergence of this model creates fundamental conditions for achieving a terminological revolution in productive forces. The new qualitative state of productive forces requires empowerment through breakthrough and disruptive technologies, along with the establishment of a supply system for general-purpose technologies. This, in turn, enables structural leaps in the combination of productive factors and supports the rise of strategic emerging industries, thereby advancing the transition from a terminological revolution to a qualitative transformation. In summary, the system of tools of production, the system of energy resources for production, and the internal contradictory dynamics within them drive the optimization and transformation of the combination of factors of production, thereby propelling the formation of NQPFs. The synergistic development of digital NQPFs and green NQPFs constitutes both the integrated growth mechanism and the cyclical pattern of NQPF formation.

3.2 Transformation of core productive factors and the emergence of a new "techno-economic paradigm"

Productive forces constitute an organic system composed of multiple factors, each with its own specific structure and function. Within this system, the quality of individual productive factors, the quality of their combinations and the quality of the materialized outcomes of productive forces are the primary determinants of the overall quality of productive forces (Ren, 2018). Among these, the structure of productive factors is the most crucial in determining the qualitative state and level of advancement of productive forces. Technological revolutions and

industrial transformations generate clusters of innovation and new industrial agglomerations, altering the structure of productive factors and thereby giving rise to a new "techno-economic paradigm". The formation of NQPFs is not merely an iteration of traditional productive forces but involves a fundamental qualitative change in the structure of productive factors.

Productive factors can be categorized into two types. The first type consists of tangible factors, including laborers, means of labor, and objects of labor. Among these, laborers are the most dynamic element, while means of labor and objects of labor provide the material conditions for laborers' productive activities. Tangible factors serve as the material carriers that sustain the existence and functioning of other factors. The second category comprises non-material elements, such as science and technology, education and management, which function as penetrative factors within the structural composition of productive forces. They exert their influence by enhancing the qualitative attributes of the material elements. Among all intangible factors, the evolution of science and technology is the fundamental driver of structural leaps in productive factors, as it enhances the performance of laborers, the means of labor and organizational management within the system of productive forces. In this sense, science and technology constitute the primary productive force and the disruptive innovations generated by technological revolutions are the core elements in the formation of NQPFs. Therefore, from a theoretical perspective on the formation of NQPFs, they represent a new "techno-economic paradigm" arising from structural transformations of productive factors driven by technological innovation.

The transformation of the structure in NQPFs is primarily reflected in the disruptive changes in science and technology, the core productive factor, which in turn induces qualitative changes in other productive factors. The formation of a new "techno-economic paradigm" is essentially the result of disruptive technological change, introducing new productive factors into the system of productive forces. The history of human social development is essentially a history of technological development. Technological revolutions introduce new productive factors into the system of productive forces, causing qualitative changes in the tangible factors of traditional productive forces, which in turn lead to systemic restructuring of production methods and adjustments in the form of industrial organization. Productive forces also function as systemic capacities, with dominant and non-dominant elements within different systems; the dominant elements exert a decisive influence. As Marx (2009, p. 31) noted: "There is in every social formation a particular branch of production which determines the position and importance of all the others, and the relations obtaining in this branch accordingly determine the relations of all other branches as well. It is as though light of a particular hue were cast upon everything, tingeing all other colors and modifying their specific features". In the digital economy era, technological change primarily manifests as the replacement of human mental labor with digital and intelligent technologies, necessitating corresponding changes in traditional productive factors.

With breakthroughs in digital and intelligent technologies, a new productive factor emerges: data. Data enhances efficiency by empowering technologies, machinery, capital, and labor (Zhang, 2021) and endows traditional tangible factors with new significance, thereby constituting NQPFs. In the digital economy era, technological empowerment overcomes the intellectual limitations of traditional laborers, creating new quality laborers. The most important laborers in the digital era are knowledge producers who can drive disruptive innovation. Labor driven by data is more complex than traditional labor, particularly as innovations in AI and human–machine integration expand the boundaries of human capabilities. Human creativity and AI mutually reinforce one another, producing a divergent innovation paradigm that shortens the iteration cycles of cutting-edge technology and significantly reduces the lag between technological revolutions and industrial transformations – a fundamental change brought about by new quality laborers.

The combination of digital and intelligent technologies also catalyzed the emergence of new tools for intelligent production. Digital technologies – such as the Internet, the Internet

of Things, quantum communications, big data and blockchain – facilitate the interconnection of all things, generating vast amounts of analyzable data. Intelligent technologies, including integrated circuits and AI, enable scientific analysis and precise decision-making based on these massive datasets. Together, they intellectualize the means of labor, augment and extend human intellectual capabilities and spark a new revolution in productive forces. Empowered by digital and intelligent technologies, traditional energy-conversion tools – which in an industrial society primarily served as engines and operating machines – are now equipped with sensing, computing, communication and control systems. This integration drives a qualitative transformation of these tools, significantly expanding and elevating human creative activities. Smart tools empowered by data constitute new quality means of production.

New quality objects of labor manifest as digital information measured in bits, as well as the integrated elements resulting from their enabling effect on traditional objects of labor. Material, energy and information form the three foundational resources of human society, around which the development of human society revolves through their exploitation and utilization. The deep embedding of data as a factor upgrades objects of labor from physical materials and energy to a composite of "natural objects + artificially created objects + virtual digital symbols". Under data empowerment, objects of labor exhibit characteristics of physical-virtual integration (Zheng and Zhou, 2023). Data-empowered integrated elements constitute the core of new quality objects of labor, as in the digital era, the operation of the entire economy and society is underpinned by digital information and its integrated elements.

3.3 The green transformation of productive forces driven by the energy revolution

The formation of NQPFs not only manifests in the substantial enhancement of productive forces driven by the embedding of data as a factor but also relies crucially on breakthroughs in renewable energy technologies to form green productive forces. The development of these green productive forces gives rise to green wealth, a concept that promotes innovation in wealth theory. This trajectory is determined by the inherent logic of technological evolution, which dictates that advancements in tool-based technologies must align with transformations in energy technologies. The formation of NQPFs constitutes a revolution in productive forces, characterized by simultaneous breakthroughs in both tool technologies and energy technologies: The former enhance productivity but dissipate energy, while the latter supply the necessary power. For example, during the IR1.0, textile machinery initiated the "mechanization" of industry, while coal and the steam engine enabled its widespread diffusion. Thus, each industrial revolution entails at least two categories of technological innovation: one led by energy-dissipating instrumental technologies and the other by energy-supplying power technologies. Viewed through the lens of economic development paradigm shifts, each breakthrough in tool technology triggers a significant expansion in energy demand, which leads to a substantial increase in the energy intensity of both production and human lifestyles, accelerating the extraction of natural energy and enabling human societal systems to achieve a form of entropy reduction, thereby disrupting traditional equilibria and facilitating a qualitative transformation of productive forces within a new "techno-economic paradigm".

Compared with the industrial economy, the digital economy constitutes not only a revolution in the productive forces but also a "techno-economic paradigm" with significantly higher energy intensity. In the digital economy era, tool-based technologies are digital and intelligent; however, these remain energy-dissipative technologies, while current energy-supply technologies have not yet experienced a fundamental breakthrough. This phenomenon aligns with the evolutionary pattern of technological revolutions: tool-based revolutions always precede energy revolutions, while energy revolutions typically emerge in the latter phase of industrial revolutions and continue to act as leading industries in the energy sector during the first half of the next industrial revolution (Jia, 2016). Thus, technological evolution invariably demands access to higher-density energy sources, but energy revolutions generally lag behind tool-based revolutions.

With the continuous advancement of digital and intelligent technologies, the development of new energy-supply technologies has become imperative, manifesting in two key dimensions: energy demand and energy cost. On the demand side, the energy needs generated by the new wave of technological revolution in the digital economy era far exceed those of the industrial economy, while traditional fossil energy sources are gradually depleted. Therefore, the constraining technology for the formation of NQPFs in the digital era may no longer be digital technologies themselves but rather energy technologies. For example, the electricity consumed by the development of AI has already far surpassed our initial expectations, and future progress in AI may require major breakthroughs in new energy technologies as a precondition. Moreover, the energy consumption patterns of the past two industrial revolutions have already caused severe ecological and environmental problems, and the wave of the information technology revolution since the late 20th century has not provided effective solutions to these problems. If the energy supply for digital and intelligent technologies continues to rely primarily on fossil fuels, it will further exacerbate environmental degradation, diminishing the quality of the ecological conditions essential for human survival and development.

Against this backdrop, the formation of NQPFs entails a green technological revolution. Represented by renewable energy technologies, this green revolution constitutes the defining feature of the new round of industrial revolution. As futurist Rifkin (2011) observed, "Internet technology and renewable energies were about to merge to create a powerful new infrastructure for a Third Industrial Revolution (TIR) that would change the world". The disruptive innovation and large-scale adoption of renewable energy technologies are not only the ultimate solution to ecological challenges such as energy depletion and environmental pollution but also the indispensable pathway for the industrialization of the new wave of digital and intelligent technologies.

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