A Study on the Structural Mechanism of Technological Revolutions and Global Inequality from the Perspective of Information Science

Zhang Kun

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Abstract

[Purpose/Significance] This paper attempts to construct a unified framework from the perspective of intelligence studies to analyze the transmission laws by which scientific and technological revolutions change the information landscape and reconstruct power relations. It discusses the generation and entrenchment mechanisms of global inequality from the perspective of intelligence asymmetry, providing insights for late-developing countries to break through dependent development and achieve strategic autonomy in the era of artificial intelligence. It argues that the analytical logic of intelligence studies is applicable not only to specific decision-making scenarios but also has strong theoretical potential for explaining the interaction between information and power in the transformation of human civilization. This both expands the disciplinary vision of intelligence studies and tests its capacity to respond to national strategic needs. [Method/Process] This paper adopts a progressive approach of theoretical deduction, framework construction, and historical verification. Starting from the basic proposition in intelligence studies of "reducing information uncertainty and forming decision-making advantages," it deduces the logical chain of "technology changes the information landscape, and information asymmetry is transformed into power advantage," and constructs a three-dimensional "Technology-Information-Power" (TIP) analytical framework. It then uses this framework to conduct a historical comparative analysis of the Agricultural Revolution, the two Industrial Revolutions, the Information Revolution, and the Artificial Intelligence Revolution. From the three dimensions of T, I, and P, it systematically deconstructs the structural relationship between Western scientific and technological superiority and the dependent development of late-developing countries. [Results/Conclusions] The social impact of successive scientific and technological revolutions can be analyzed through a transmission path in which technological breakthroughs drive changes in information paradigms, information advantages reshape power structures, and these ultimately become entrenched as inequalities in the global spatial order. The bidirectional drive of technology and information and the differentiation of intelligence capabilities, the bidirectional construction of information and power and the solidification of social order, and the reconstruction of the global information order and the locking-in of the center-periphery structure together constitute the deep mechanisms through which global inequality is continuously reproduced.

Full Text

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Construction Based on the TIP Framework

Zhang Kun

(Library of Handan University, Handan 056000, Hebei, China)

Abstract: [**Purpose/Significance**] From the perspective of information science, this paper attempts to construct a unified framework to analyze the transmission laws by which scientific and technological revolutions transform information landscapes and restructure power relations. From the perspective of information asymmetry, it discusses the mechanisms through which global inequality is generated and solidified, thereby offering insights for late-developing countries seeking to break through dependent development and achieve strategic autonomy in the era of artificial intelligence. It argues that the analytical logic of information science is applicable not only to concrete decision-making scenarios, but also has strong theoretical potential for explaining the interaction between information and power in the transformation of human civilization. This is both an expansion of the disciplinary horizon of information science and a test of its capacity to respond to national strategic needs. [**Method/Process**] This paper adopts a progressive approach of theoretical deduction, framework construction, and historical verification. Starting from the basic proposition in information science of "reducing information uncertainty and forming decision-making advantages," it deduces the logical chain whereby "technology changes the information landscape, and information asymmetry is transformed into power advantage," and constructs a three-dimensional analytical framework of "technology—information—power" (TIP). It then uses this framework to conduct a historical comparative analysis of the agricultural revolution, the two industrial revolutions, the information revolution, and the artificial intelligence revolution. From the three dimensions of T, I, and P, it systematically deconstructs the structural relationship between Western scientific and technological advantages and the dependent development of late-developing countries. [**Results/Conclusion**] The social impact of successive scientific and technological revolutions can be analyzed through the transmission path whereby technological breakthroughs drive changes in information paradigms, information advantages reshape power structures, and these ultimately become solidified as inequality in the global spatial order. The bidirectional drive between technology and information and the differentiation of intelligence capabilities, the bidirectional construction of information and power and the solidification of social order, and the reconstruction of the global information order and the locking-in of the center-periphery structure together constitute the deep mechanisms through which global inequality is continuously reproduced.

Keywords: information science; scientific and technological revolution; technology-information-power framework; information asymmetry; global inequality

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A Study on the Structural Mechanism of Technological Revolutions and Global Inequality from the Perspective of Information Science: Construction Based on the TIP Framework

Zhang Kun

(Library of Handan University, Handan 056000, Hebei, China)

Abstract: [**Purpose/Significance**] This paper tries to develop a unified analytical framework, from an information-science perspective, to analyze the mechanisms of transmission through which scientific and technological revolutions transform information landscapes and reorganize power relations. From the perspective of information asymmetry, it investigates how global inequality is produced and entrenched, and thus provides clues for latecomer countries to escape the logic of dependent development and pursue strategic autonomy in the artificial intelligence era. It is argued that the analytical logic of information science, not only for dealing with specific decision-making situations, has strong theoretical potential to interpret the interplay between information and power in the evolution of human civilization. This is not only an extension of the disciplinary horizon of information science, but also a test of the capability of information science to respond to national strategic needs. [**Method/Process**] This paper goes

Author Biography: Zhang Kun (1989), male, librarian. Main research areas: information science and library science. E-mail: lakun@126.com

Affiliation: Handan University, No. 530 Xueyuan North Road, Handan, Hebei Province, Postal Code 056000

within a validation framework of theoretical deduction, system construction, and historical testing. Starting from the basic proposition of information science—"reducing information uncertainty creates decision-making advantages"—it deduces the logical link whereby "technology reshapes the information landscape, and information asymmetry is transformed into power advantages," and constructs a three-dimensional practical analytical framework of Technology-Information-Power (TIP). Subsequently, this framework is used to conduct a comparative historical analysis of the agricultural revolution, the two industrial revolutions, the information revolution, and the artificial intelligence revolution. On the basis of the three dimensions of T, I, and P, it systematically deconstructs the structural relationship between Western technological advantage and the dependent development of late-developing countries. [Results/Conclusion] The social influence of successive scientific and technological revolutions can be understood through the following transmission pathway: technological innovation drives the evolution of information paradigms; the concentration of information advantages reconfigures power relations; and this ultimately embeds inequality into the global spatial order. The mutual reinforcement between technology and information, together with differentiation in intelligent capabilities; the mutual construction between information and power, together with the solidification of social order; and the reconstruction of the global information order, together with the structural locking-in of the center-periphery relationship, jointly constitute the deep-seated mechanisms through which global inequality is continuously reproduced.

Keywords: Information Science; Technological Revolution; Technology-Information-Power Framework; Information Asymmetry; Global Inequality

From the domestication of crops that initiated agricultural civilization to the steam engine that triggered the wave of industrialization; from electricity and networks that transformed production and daily life to artificial intelligence technologies that now permeate economic and social operations in all respects—as factors at the level of productive forces and the economic base, changes in science, technology, and industry are the most fundamental driving forces behind the evolution of production relations and the world pattern and international order at the level of the superstructure[^1]. Yet history has also repeatedly and clearly shown that every wave of technological transformation, while bringing enormous potential for development, may also further widen inequalities both among countries and within them[^2]. "The new round of scientific and technological revolution and industrial transformation is advancing in depth, opening up new prospects for human society; at the same time, the global development deficit is widening, and the digital and intelligent divides urgently need to be bridged"[^3]. The revolution in general-purpose artificial intelligence technology is exerting an unprecedented impact on social structures and employment systems. Changes in the new round of global scientific and technological division of labor and in the international order are more systemic and more difficult to predict. How to seize opportunities, guard against risks, and pursue inclusive development has become a strategic issue that all countries must take seriously.

The social impact of scientific and technological revolutions is multidimensional: modes of production, social relations, cultural concepts, and everyday life are all profoundly reshaped. Yet power is the core mechanism running through the economic, political, and social domains: economic inequality is the result of the asymmetric distribution of economic power[^4]; political dependency is the result of structural bias in political power[^5]; and the solidification of social strata is the result of the intergenerational reproduction of social power[^6]. From the perspective of information science, the root of these changes in power lies in the fact that scientific and technological revolutions alter the ways information is produced, circulated, and controlled, thereby giving rise to information asymmetry. The aim of this paper is to analyze the transmission law of "information → power" and, through this lens, to deconstruct the mechanisms by which global inequality is generated and solidified.

The world today is in a new stage in which scientific and technological revolutions are reshaping social structures, thus giving rise to several fundamental questions: What are the internal laws by which scientific and technological revolutions shape social structures? Is there a stable connection between Western technological leadership and the dependent poverty of developing countries? Will the artificial intelligence revolution exacerbate,

entrench the global pattern of inequality? For late-developing countries, clarifying these laws and connections, and designing forward-looking and operable strategic pathways accordingly, has strong theoretical and practical significance.

Existing research has proceeded from single dimensions such as economics and sociology, and lacks a systematic analysis, from the perspective of intelligence studies, of the internal logic by which technological revolutions reshape social structures and intensify global inequality. In recent years, the intelligence-studies community has developed several mutually resonant and valuable research pathways for macro-social analysis: Dedijer' s idea of "social intelligence" was the earliest to directly link intelligence capability with imbalances in national development[7]; the empirical studies of Van Dijk and Ragnedda revealed how information inequality leads to the differentiation of social power, laying a foundation for research on the social consequences of the digital divide[8]; Gill defined intelligence as "knowledge and power as surveillance" [9], thereby giving rise to incisive discussions by the Critical Intelligence Studies community on intelligence as a socially constructed phenomenon of power; and Black' s historical research on information has offered an excellent interpretation, from a historical dimension, of the deep coupling between methods of information management and state power[10]. These pathways differ in their angles of entry, but all point to the same core insight: the asymmetric distribution of intelligence capability is one of the important sources of the differentiation of social power. At present, however, most studies focus on specific historical periods, such as the digital revolution, or on specific domains, such as national security, and there remains a lack of a theoretical tool capable of incorporating the five technological revolutions into a unified analysis. Therefore, the three-dimensional "Technology–Information–Power" (TIP) analytical framework proposed in this paper explores the expansion of the application boundaries of intelligence-studies theory, promotes dialogue between intelligence studies and disciplines such as history, sociology, and political science, and attempts to provide cognitive support for national strategic anticipation and forward-looking planning amid changes unseen in a century. On this basis, the research objectives of this paper are:

1. To establish an intelligence-studies theoretical framework suitable for analyzing the social impacts of technological revolutions.

2. To analyze, from the perspective of intelligence studies, the common laws and period-specific heterogeneity of successive technological revolutions.
3. To trace the mechanisms of global inequality from the perspective of intelligence studies.
4. To derive implications for the strategic choices of late-developing countries in technological revolutions.

This paper develops its discussion along the logical thread of "theoretical construction—historical testing—mechanism deconstruction—strategic implications," exploring how to analyze the social impacts of technological revolutions from the perspective of intelligence studies.

1 Technology-Information-Power: An Intelligence-Studies Analytical Framework

The object of intelligence-studies research is the universally existing social phenomenon of intelligence and the entirety of intelligence communication activities[11]. From the disciplinary standpoint of intelligence studies, technological revolutions should not be regarded merely as replacements of the means of material production, but should instead be understood as systemic changes in information forms, modes of information flow, and capacities for information control. To this end, this paper attempts to integrate information-chain theory, competitive-intelligence thought, and the social perspective of intelligence analysis, constructing an intelligence-studies analytical framework for the study of technological revolutions: the Technology-Information-Power (TIP) framework. This framework takes as its starting point the logic of theoretical deduction from the core propositions of intelligence studies itself.

1.1 The Basic Proposition of Intelligence Studies: Information, Uncertainty, and Decision-Making Advantage

Intelligence is activated, actionable knowledge[12]. By purposefully collecting, organizing, and analyzing information, uncertainty faced in decision-making is reduced, thereby forming an intelligence advantage and transforming that advantage into actual capacity for action. This is the practical point of origin of intelligence studies. This proposition does not depend on any particular technological condition; it is the basic function of intelligence work in all competitive environments.

Information theory regards the difficulty of decision-making as lying in the uncertainty of system states. Shannon' s information-entropy formula, $S = -\sum p_i \ln p_i$, provides a way to measure such uncertainty: the higher the entropy, the more chaotic the event state, the greater the uncertainty, and the more difficult the decision-making becomes[13]. Therefore, the fundamental purpose of intelligence work is to actively collect and analyze information in specific decision-making situations, reduce the entropy in that situation, and enable actors' judgments to move from probabilistic guessing toward evidence-based foresight.

The paths through which intelligence advantage is transformed into decision-making advantage are as follows. First, fuller and more accurate information helps reduce actors' blind spots in understanding the state of the system[14]. Second, systematic investigation of the correlations, tendencies, and causalities among information can reveal patterns that are difficult to detect through ordinary observation[15]. Third, by exploiting the time-difference advantage in information acquisition and processing, actors can occupy a favorable position before their opponents respond[16]. Fourth, the information generated by the outcomes of action feeds back into subsequent decisions, thereby forming a complete cycle of "information—judgment—action—re-information" [17]. It is worth noting that manual intelligence in the agricultural era, statistical surveys in the industrial era, and network monitoring in the information era all follow this logical chain; only the technical means employed and the efficiency of implementation differ.

Dedijer, Black, Van Dijk, Ragnedda, and others have all extended intelligence studies to the scale of macrohistory. On the basis of inheriting and integrating various pioneering achievements, this paper explores the transformation of the core propositions of intelligence studies into a unified framework applicable to comparative analysis of the five scientific and technological revolutions. It attempts both to test the theoretical validity of this framework in long-period macrohistorical interpretation and to explore the internal mechanism by which power inequality moves from "triggering" to "locking in."

1.2 Bidirectional Relationship Between Information Advantage and Power Advantage

Information is an important source and instrument of power, but information advantage itself is not equivalent to power; it must be transformed before it can generate dominance[18]. **Resource redistribution:** Since actors who possess more and more accurate information can more fully and promptly discover resources undervalued by society, they are able to acquire higher value at lower cost[19]. Thus, the long-term accumulation of information rents inevitably results in the concentration of wealth, technical capabilities, and various resources among those rich in information[14], which is the basis of economic power. **Rule shaping:** After information advantage reaches a certain level, actors are more likely to discover the loopholes and inefficiencies of existing institutions, and thus are also more likely to propose alternative rules. In essence, rule-making power is an advanced form of power; once established, it can exert its effects by means of institutional inertia[20–21]. **Self-reinforcement of reputation and trust:** Continuously correct decisions help accumulate the reputation of individuals or organizations, giving their opinions greater weight in collective choices. Such influence can often be incorporated into the explanatory framework of the "expert power/referent power" described by French & Raven, and may gradually solidify within organizations, becoming a relatively stable and predictable source of influence[22]. The "signaling—screening" theory proposed in intelligence studies provides an excellent supplementary explanation for this: high-quality intelligence products are themselves reliable signals of capability; they can therefore reduce transaction costs and more easily attract collaborators[14]. These three mechanisms show that, once information advantage accumulates to a certain critical level, it will transform from an individual and incidental decision-making advantage into a structural and institutional control capacity.

Once power advantage is formed, it in turn consolidates and expands information advantage, creating a positive-feedback closed loop of "information → power → information." First, there is the power to define information standards. Rule-making power enables power holders to define "what counts as credible information," "what counts as compliant data," and "what counts as frontier knowledge." Second, there is the power to control information infrastructure. Rule-making power enables power holders to control the material carriers through which information circulates, ensuring that the asymmetric pattern of information flow continues to tilt toward themselves. Third, there is the power to shape cognitive frameworks. Actors who continuously possess information advantage see their opinions gain greater weight in collective choices, gradually forming "expert power" or "referent power."

Information advantages become power advantages through the reallocation of resources, the creation of rules, and the accumulation of reputation (I→P). Power advantages, in turn, further reinforce information asymmetry by defining information standards, controlling information infrastructure, and shaping cognitive patterns (P→I). Thus, information advantages and power advantages stand in a mutually constitutive relationship.

1.3 Bidirectional Driving Between Technological Capability and Information Capability

Intelligence studies must answer the question of where information comes from. At present, technology—that is, the means of acquiring, storing, transmitting, processing, and analyzing information—is the principal pathway for improving information capability[12]. From the perspective of intelligence studies, technology is not an element independent of the intelligence system; it is a decisive variable affecting efficiency at every stage of the information chain (collection, organization, analysis, and use)[15]. The influence of technology on information capability can be understood from the following angles: 1. Collection technologies can broaden the coverage of information and make data more accurate, thereby eliminating decision-making blind spots caused by insufficient information. 2. Storage technologies help extend the retention time of information, improve retrieval efficiency, and enable trend analysis using historical data. 3.

Processing technologies facilitate data cleaning, integration, and transformation, greatly shortening the cycle from raw data to usable intelligence. 4. Analytical technologies (statistical methods and various machine-learning methods) can mine latent patterns from massive data, identify relationships among variables, and advance intelligence products from description to prediction. 5. Communication technologies facilitate information sharing and collaborative analysis, forming collective intelligence advantages.

Information, in turn, guides and accelerates the evolution of technology (I→T). Actors that possess frontier scientific and technological intelligence, patent-layout information, and market-demand information can identify key bottlenecks in technological systems and concentrate limited R&D resources on the directions most likely to yield breakthroughs. Information can provide a "gene pool" for technological combinations. In *The Nature of Technology*, W. Brian Arthur argues that all technologies are recombinations of existing technological modules. Whoever possesses more complete information about the technological gene pool can combine new technologies more quickly[23]. Information is non-rivalrous and has low reproduction costs; a piece of key intelligence can be used an unlimited number of times without being depleted. By obtaining technological information from pioneers, latecomers can skip the trial-and-error stage and move directly into technological improvement and application.

The complete relationship between information and technology is bidirectionally driven: technological progress provides the material basis for enhancing information capability (T→I), while information, in turn, serves as a navigator for technological R&D, a raw material for combination, and an accelerator of efficiency (I→T).

1.4 Bidirectional Interaction Between Power Structures and Technological Trajectories

Power influences or controls technological trajectories (P→T). Once the authority to formulate rules is conferred, power can directly or indirectly affect technological R&D, standards, and pathways. The authority to formulate rules determines the direction of technical standards; the composition of technical committees in international standards organizations, the scope of protection under patent systems, and the regulatory lists for technology trade are all decided by core states that possess rule-making power, thereby producing a phenomenon of path lock-in. Intellectual-property agreements (TRIPS), rules on cross-border data flows (GDPR), and additional conditions attached to technological assistance all use institutional means to restrict peripheral countries, creating a trap of emergency learning and causing institutional arrangements to impose constraints on the acquisition and use of technology. Cognitive frameworks determine, to a certain extent, whether a technology is advanced and worthy of investment; through academic evaluation systems, industrial-policy discourse, and technology roadmaps, power constructs a worldwide consensus on the direction of technological progress.

Technology provides new tools for power (T→P). The guidance of technology by power is not a one-way control—once a new technology is born, it in turn provides unprecedented means for the exercise of power, continuously upgrading the scope of penetration, precision, and concealment of power[24]-[27]. Each technological breakthrough

will all broaden the places that power can reach—from the workshop to consumer behavior, and from physical space to psychological space. Traditional uses of power were extensive and coarse-grained; in the digital age, tools of power have become highly precise, increasing the accuracy of power. Technology makes power invisible and strengthens its concealment, and thus makes it easier to be discovered, questioned, and checked. Power both shapes people' s preferences and cognition and embeds this shaping into the very operation of technology itself, so that the form of power is enhanced within technology. Power relies on rule-making, institutional arrangements, and cognitive frameworks to constrain technological trajectories (P → T); technology, by expanding its scope of penetration, improving precision, and strengthening concealment, provides new tools for power (T → P). Between the two there forms a cycle of mutual constraint and mutual empowerment.

1.5 Integrated Statement of the TIP Framework and Analytical Procedure

Synthesizing the above derivation, the complete logical chain of the TIP framework can be obtained:

The three dimensions of T, I, and P are arranged in a mutually nonlinear manner, forming a triangular structure of bidirectional interaction. As shown in Figure 1, the T—I side represents the bidirectionally driven relationship between technology and information (technology changes the information landscape, and information feeds back into technology); the I—P side represents the bidirectionally constructed relationship between information and power (information advantage is transformed into power, and power consolidates information asymmetry); and the P—T side represents the bidirectionally constraining relationship between power and technology (power guides and restricts technological trajectories, while technology provides new tools for power).

[Text in Figure 1]

- **Technology T**
  Determinant variable of information-chain efficiency
  Collection ・storage ・processing ・analysis ・dissemination
- **Information I**
  Reduces uncertainty
  Builds intelligence advantage
  (key intermediary hub)
- **Power P**
  With "rule establishment" as its core

State ・social strata ・global space
Threshold transition P_{th}
From competitor → rule-maker

- **T→I primary transmission**
  Technology changes the information landscape
- **I→T feedback**
  Information feeds back into the direction of technology
- **T→P feedback**
  Technology provides new tools for power
- **P→T primary transmission**
  Power guides/restricts technological trajectories
- **I→P primary transmission**
  Information advantage is transformed into power
- **P→I feedback**
  Power consolidates information asymmetry

Figure 1. Diagram of the TIP Triangle Framework

Figure 1. TIP Triangle Framework

Because the abstract framework discussed here is to be applied to research on scientific and technological revolutions, a three-step analytical procedure is designed:

T dimension: the technology-information triggering end. Theoretically, this examines how dominant technology clusters change the efficiency of each link in the information chain—collection, storage, processing, analysis, and dissemination—and thereby derives their fundamental influence on the subjects of information production, distribution structures, and the speed of flows. The driving effect of technological input on information capabilities has a clear characteristic of increasing returns to scale, so it can be taken as the triggering end of the "technology-information-power" chain. At the same time, the intelligence advantage from the I dimension has a selective and feedback effect on the direction of technological R&D (I → T), forming the first loop of a positive-feedback closed circuit.

I dimension: the intermediary end of information-power conversion. Beginning with the transformation of the information paradigm triggered by technological breakthroughs, this examines changes in modes of information control and the resulting pattern of social intelligence asymmetry, yielding a clear conclusion: intelligence asymmetry is the key intermediary through which technological advantage is transformed into power advantage. Whoever identifies opportunities first and avoids risks first occupies a favorable position. At the same time, the power structure from the P dimension, by controlling the definitional standards, flow rules, and credibility of information, reversely reinforces the existing pattern of information asymmetry (P → I).

P dimension: the power-structure solidification end. Intelligence asymmetry is transformed into structural control capacity. At the same time, power should be defined as a capacity for domination whose unified core is the establishment of rules, and should be examined at the three levels of the state, social strata, and global space. It is proposed that when the accumulation of power reaches a certain threshold (Pth), actors leap from competitors to rule-makers and enter a new growth trajectory. Once power is formed, it is used to define rules and, in reverse, to lock in the information structure and the direction of technological innovation, thereby forming a complete closed loop of "triggering—lock-in."

1.6 Core Dynamic Characteristics of the TIP Framework

The TIP framework reveals a bidirectional closed-loop structure among technology, information, and power. Based on historical comparative analysis, this paper uses Figure 2 to represent the co-evolutionary trajectories of information accumulation, information asymmetry, and power restructuring across successive scientific and technological revolutions.

The solid line represents the level of information accumulation, showing stepwise S-shaped growth, with the slope briefly increasing after each revolution. The dashed line represents the degree of information asymmetry, displaying a sawtooth pattern of sudden drop, rapid rebound, and surpassing the previous high, while the long-term baseline gradually rises. The dash-dotted line represents the level of power restructuring, which begins S-shaped growth after a revolution and undergoes a structural leap at the moment when rule-making power is obtained; the vertical dotted lines mark the outbreak points of scientific and technological revolutions.

[Figure: line chart titled "Information Asymmetry: Revolution Drop → Rebound → Step Rise," with legend entries "Information Accumulation," "Power Restructuring," and "Information Asymmetry" ; axes labeled "Time," "Information & Power," and "Asymmetry" ; vertical markers labeled "REVOLUTION 1," "REVOLUTION 2," and "REVOLUTION 3" ; points labeled "JUMP 1," "JUMP 2," and "JUMP 3."]

Figure 2. TIP Cyclic Evolution

Figure 2. Cyclic Evolution of the TIP Framework

This figure shows that the TIP framework has three main dynamic characteristics: a positive-feedback cycle, threshold leaps, and sawtooth stepwise evolution of inequality. Technological progress enhances information capacity ($T \to I$); those who first master information advantages occupy a favorable position when making decisions, and this then becomes power ($I \to P$). Power maintains information asymmetry through rule creation and resource allocation ($P \to I$), while information asymmetry in turn guides the direction of technology ($I \to T$). These three elements influence one another, accumulating and expanding, thereby producing a cumulative effect in which the strong become ever stronger. (2) Threshold leaps. The accumulation of information asymmetry and power is not linear. After the two pass a critical point, actors change from rule-followers into rule-makers; power undergoes discontinuous structural change, and roles change fundamentally. Once this threshold is crossed, the original first-mover advantage is fixed in place by institutions, making it very difficult for latecomers to reverse their position. (3) Sawtooth stepwise evolution of inequality. Each scientific and technological revolution temporarily breaks through the old information monopoly in the diffusion of core knowledge, causing the degree of inequality to decline, but this is only temporary. The pioneers soon use data control, standard-setting, and other methods to re-establish information barriers stronger than before; the inequality curve then begins to rise again and exceeds the original

level. As multiple scientific and technological revolutions accumulate, the baseline of information asymmetry is lifted upward in a stepwise manner, and inequality worldwide also shows a serrated upward trend. In short, the figure illustrates the entire historical cycle encompassed by the TIP framework: long-term information accumulation triggers a scientific and technological revolution, breaks the original intelligence asymmetry, reorganizes a new asymmetrical pattern, and then information accumulates again and enters the next cycle.

2 Common Laws and Era-Specific Heterogeneity of Information Order and Power Reconstruction in Scientific and Technological Revolutions

Information is not something new that appeared only in the digital age; rather, it is a main thread running through human civilization. Agricultural society relied on calendars, farming seasons, and knowledge of land; the industrial era depended on technical principles and management norms; and the information age cannot do without data and algorithms. Ultimately, these are all forms in which information manifests itself at different historical stages. Therefore, the agricultural revolution, the industrial revolution, and the information revolution can all be placed within the same information-analysis framework. Every major scientific and technological revolution changes the informational attributes of the dominant factors of production at the time, thereby changing who produces information, how it is disseminated, and by whom it is controlled. Ultimately, gaps in intelligence capacity emerge among different countries and different social strata. As these gaps gradually widen, they lead to a reshuffling of social classes, national strength, and the global spatial order (as shown in Figure 3).

2.1 Technological Breakthroughs Bring About the Informatization Transformation of Factors of Production

Scientific and technological revolutions are marked by breakthroughs in dominant technological clusters. Technologies such as the steam engine, electricity, computers, and artificial intelligence not only improve production efficiency, but also place new factors of production at the core of economic and social operation. From the perspective of intelligence studies, the core factors of production in successive revolutions have exhibited increasingly strong informatization characteristics: the agricultural revolution was accomplished through the integrated use of biological information, climatic knowledge, and land resources; the industrial revolution was realized through the engineering application of physical information such as mechanical energy and chemical energy; the information revolution treated data, networks, and software as the main factors of production; and the age of artificial intelligence places three elements—algorithms, computing power, and high-quality data—at the core. These stages inherit from one another and advance layer by layer, and their fundamental differences lie in the continuous changes in information density, carriers, modes of flow, processing capabilities, and other aspects. Therefore, this is consistent with the internal logic that "technological change alters the information structure, and information asymmetry leads to power differentiation" [14]. Using a unified intelligence-studies logic to explain the entire process from the agricultural revolution to the artificial intelligence revolution provides an analytical perspective for scientific and technological revolutions and changes in the global order. This is the fundamental value of this paper' s "Technology-Information-Power" (TIP) framework.

2.2 The Reconstruction of Information Paradigms Drives the Formation and Self-Reinforcement of Intelligence Asymmetry

An information paradigm refers to the main ways in which information is produced, disseminated, controlled, and used within a given period. Technological innovation changes the forms in which information exists and the ways in which it flows, thereby causing major changes in the information paradigm. Printing expanded information production from monastery scribes to printing workshops; the telegraph shortened the speed of information flow from the several weeks required by messengers to only a few seconds; the Internet expanded information producers from a small number of institutions to every user; and artificial intelligence has further transformed information producers from humans into machines. Every scientific and technological revolution fundamentally changes the way these four relationships are combined.

The imbalance of technological diffusion is not merely a difference in technological capability, but an intergenerational gap in information capability. When technological pioneers master a new technology, they have already taken control of the information infrastructure attached to that technology, namely telegraph networks, Internet backbone nodes, cloud computing centers, and AI training platforms. These infrastructures are both technological tools and nodes for information collection, transmission, processing, and storage. Whoever controls these nodes determines which information can be obtained, at what speed it flows, and in what format it is interpreted. The imbalance of technological diffusion therefore becomes, in the information dimension, an asymmetrical distribution of control over information nodes; this is the material basis for the emergence of intelligence asymmetry.

Intelligence asymmetry is manifested here in two interrelated ways. The first is asymmetry in information acquisition: first movers control the points of information collection and channels of circulation, so latecomers, even when they have needs, cannot obtain information of the same quality or timeliness. The second is asymmetry in information interpretation: even if latecomers obtain the original information, they often lack the analytical capability, algorithmic tools, and cognitive frameworks needed to transform that original information into usable intelligence. The former is the problem of "whether information can be obtained," while the latter is the problem of "whether information can be used after it is obtained." The combination of the two means that intelligence asymmetry is not merely a temporary lag, but a structural differentiation of capabilities. Once intelligence asymmetry emerges, it tends to reinforce itself.

Those with abundant information can rely on their informational advantage to predict the direction of the next technological transformation more accurately and once again occupy favorable positions in the layout of new information infrastructure. Those lacking information, because they cannot identify which new technologies are worth investing in and which information infrastructures are worth building, remain disadvantaged in the next round of competition. This positive-feedback mechanism means that intelligence asymmetry is not a one-off event, but a continuously recurring process.

2.3 Power Reorganization Locks In Social Stratification and Reconstructs Spatial Order

Once intelligence asymmetry reaches a certain threshold, informational advantage is transformed into economic control, political discourse power, and institutional dominance. First movers exercise substantive control over the principles of core technologies, key data resources, industrial standards, and market information, thereby gaining advantages in rule-making, profit distribution, and international discourse power. On this basis, they substantively convert intelligence advantage into economic power, political power, and even institutional power. Therefore, technological revolutions are not only a concrete mechanism through which scientific and technological change drives social differentiation, but also the most direct and explicit information-science root of the formation and continuation of global inequality. More fundamentally, intelligence asymmetry is not merely an informational phenomenon; in essence, it is the structural difference among different actors in their capacities to acquire, possess, and use information, and this is the driving force behind power reorganization.

Thus, the TIP framework discusses the reshaping of power structures by technological revolutions at three levels: 1. Reorganization of social power: the status of groups that control production factors with high information density rises, while strata relying on traditional production factors are relatively weakened. 2. Reconstruction of state power: technologically leading countries use technological advantages, patent barriers, and dominance over standards as means to actively shape global divisions of labor and international rules that favor themselves; national hegemony is thereby formed, producing a center-periphery global structure. 3. Imbalance of spatial power: because both technology and information are concentrated as advantages, global wealth, innovation resources, and high-end factors all cluster in a small number of regions, thereby greatly intensifying inequality in global spatial development.

Technological leap (Technology)
(informatization of production factors; breakthroughs in core technologies)

↓

Information paradigm transformation (Information)
(restructuring of information flows; expansion of intelligence asymmetry; formation of knowledge monopolies)

↓

Reshaping of power structures (Power)
(class reorganization; national hegemony; spatial inequality; formation of a global center-periphery structure)

↑ Informatization of production factors ↑ Intelligence asymmetry and monopoly ↑ Inequality in the global order

Figure 3. Technological leap-information paradigm transformation-intelligence asymmetry-restructuring of power structures

Fig. 3 Tech leap, info paradigm shift, intel asymmetry, power restructure

2.4 Common Laws Based on the TIP Framework Transmission Mechanism

Although the manifestations of successive scientific and technological revolutions differ, their evolutionary processes share three laws, as shown in Table 1; they are therefore summarized systematically as follows.

Law 1 (T I): bidirectional driving between technology and information. Technology and information exhibit a clear bidirectional driving relationship, which can be observed in all five revolutions. During the Agricultural Revolution, calendar tools were invented, enabling the regular and hierarchical recording of climate patterns and agricultural timing information (T→I), which in turn guided the development direction of cultivation techniques and crop domestication (I→T). In the First Industrial Revolution, the invention of the steam engine not only improved production efficiency but also directly promoted the emergence of new information forms such as engineering drawings, technical patents, and mechanical manuals (T→I). Meanwhile, the mechanical principles and thermodynamic knowledge on which the steam engine depended were strictly monopolized by Britain, allowing Britain to maintain a long-term lead in technological improvements in the textile industry (I→T). During the Information Revolution, computers and the Internet were greatly popularized, thereby qualitatively improving the efficiency with which computers collect, store, and analyze data (T→I); analysis of network data, in turn, naturally advanced the iteration of algorithms and artificial intelligence technologies (I→T).

Successive revolutions jointly show that technological breakthroughs help enhance information capabilities, while information capabilities naturally guide technological directions; the two thus form the first engine of a positive-feedback closed loop.

Law 2 (I P): bidirectional construction between information and power. Information advantage and power advantage construct one another and influence each other, forming a clear bidirectional construction relationship. During the Agricultural Revolution, through the monopolization of knowledge concerning calendars, hydrology, and land, the priestly class and landowners acquired the power to dominate the allocation of social resources (I→P); they also consolidated the privileged position of the knowledge stratum through the monopoly of writing and the school system (P→I). During the First Industrial Revolution, industrial capitalists mastered the design principles of the steam engine and knowledge of factory management, and industrial capitalists replaced the landed aristocracy as the new power stratum (I→P). Meanwhile, the patent system and technical standards transformed their informational advantages into legally protected exclusionary rights (P→I). During the Second Industrial Revolution, the authority to formulate standards for electricity and chemical technologies was held by certain countries and enterprises, so they in effect controlled the distribution of interests across the global industrial chain. In the Information Revolution, platforms mastered user data and thereby acquired the power to define market rules (I→P), while the algorithmic recommendation mechanisms and platform rules adopted by platforms naturally strengthened users' informational dependence on them (P→I).

Successive revolutions show that information advantage can be transformed into power advantage, while power helps define information standards and determine cognitive frameworks; the two thus form the second engine of a positive-feedback closed loop.

Law 3 (T I P): restructuring of the global information order and lock-in of the center-periphery structure. Law 1 and Law 2 are superimposed at the global level, forming a triple positive-feedback closed loop of technology-information-power. In the First Industrial Revolution, Britain took the lead in fully completing the T I P loop: technological breakthroughs in steam engines and textile machinery (T) transformed the information structure of the global textile industry (T→I), thereby converting its monopoly over technical principles and trade intelligence into the authority to formulate rules for the global textile market (I→P). The latter was then consolidated through patent export prohibitions and the gold standard (P→I→T). As a result, Britain leapt from being a market competitor to becoming a rule maker, naturally incorporating other countries into the hierarchical division-of-labor system it dominated. During the Second Industrial Revolution, the United States and Germany both acted according to the same closed-loop logic; thus, both technological catch-up with Britain and rule substitution were achieved. In the Information Revolution, the United States possesses technological control over Internet infrastructure, operating systems, and search engines (T), controls the gatekeepers of global digital information flows (T→I), and therefore transforms information advantage into dominance over global digital trade rules and data-governance standards (I→P). Rule-making power, in turn, strengthens the United States' technological leadership (P→I→T).

Because of the relationship among the three closed loops, colonial legacies, international financial rules, intellectual property systems, digital platform monopolies, and algorithmic control form a five-layered composite structure. Late-developing countries are therefore caught in generational lock-in: the objects of their technological catch-up are mostly the dominant technologies of the previous generation, because the core countries have already used their rule-making power to lock in the development trajectory of the next generation of technologies.

Table 1. Common transmission laws by which technological revolutions affect social structure

Table 1. General transmission patterns of technological revolution on social structure

No.	Name	Core connotation	Corresponding T/I/P dimension
1	Bidirectional technology-information driving and differentiation of intelligence capabilities	Technological improvement enhances information capabilities; information feedback sets the technological direction; positive feedback widens capability gaps	$T \rightleftarrows I$: technology raises the information density of factors

No.	Name	Core connotation	Corresponding T/I/P dimension
2	Bidirectional construction of information–power and solidification of social order	Information advantages are transformed into power; power solidifies information asymmetry through rules and cognition	$I \rightleftarrows P$: differences in information capabilities lead to stratification
3	Reconstruction of the global information order and center–periphery structural lock-in	Bidirectional driving overlaps within the international system to form a closed loop, and inequality reproduces itself in a layered form	$T \rightleftarrows I \rightleftarrows P$ closed loop: intelligence gaps are solidified through institutions

2.5 Era-specific heterogeneity of information forms from material carriers to intelligent algorithms

Table 2 uses the three dimensions of TIP to systematically compare the information-science characteristics of the five technological revolutions. Under different technological paradigms, information forms exhibit essential differences. The carrier of information changes from matter to symbols; information control changes from direct possession to institutional discipline; and the form of inequality changes from overt plunder to covert domination. This is a developmental process that runs throughout. The three are not isolated from one another, but constitute a unified process driven by the evolution of information forms.

Evolutionary direction one: the information carrier shifts from matter to symbols. In the agricultural era, information was attached to land, oral transmission, and experience; it could not exist independently apart from physical carriers, and both replication and transmission were strictly constrained by time and space. In the industrial era, information acquired an independent material form: drawings, patent specifications, and operating manuals made it possible for information, for the first time, to exist apart from the producer and to be transmitted across time and space. In the information era, all information is digitized: text, images, and sound are all converted into bits that can be replicated at zero cost, and the speed of information transmission breaks free from the constraints of physical transport. In the artificial intelligence era, the information carrier again changes from records to models; algorithmic weights can not only preserve information, but can also create new information on their own. Overall, technological progress improves the efficiency of information collection, storage, and transmission ($T \to I$), while the improvement of information capabilities in turn accelerates the development of technology toward higher information density ($I \to T$). Each change in the information carrier reduces the cost of information replication, increases the speed of information flow, and expands the scope of information control; this is precisely the material basis on which intelligence asymmetry emerges and becomes solidified.

Evolutionary direction two: information control shifts from direct possession to institutional discipline. In the agricultural era, information control relied on the direct possession of land ownership; those who owned land controlled all biological information attached to it. In the industrial era, information control shifted toward patent systems and technical standards: control was no longer primarily based on physical possession, but on legal exclusive rights. In the information era, information control takes platform rules and intellectual property as its principal means; being controlled means having to comply with platform rules. In the artificial intelligence era, information control is further upgraded into algorithmic black boxes and model weights. Control is no longer a set of public legal provisions, but invisible rules directly embedded in technological infrastructure. Once information advantage becomes the power to make rules ($I \to P$), power

It relies precisely on defining information standards and cognitive frameworks to feed back information asymmetry ($P \to I$). The mode of control changes from direct possession to institutional regulation; in essence, this is the result of the continual institutionalization and internalization of $P \to I$ feedback. Power becomes increasingly concealed, embedded more and more in institutions and technologies rather than relying on naked violence.

Evolutionary direction three: the form of inequality shifts from explicit plunder to implicit domination. In the agricultural era, inequality manifested as ethnic expulsion and land possession, and violence was the main means by which power operated. In the industrial era, inequality took the form of colonial plunder and class differentiation; capital played an even greater role, while military conquest was the principal method. In the information era, inequality became the digital divide and producer-consumer inequality; inequality existed in different points of access to technology, and its violent character was greatly reduced. In the era of artificial intelligence, inequality becomes still more invisible: data colonialism, algorithmic hegemony, and skill gaps all become global phenomena.

This evolutionary process is **Law Three**–the closed loop ($T \rightleftarrows I \rightleftarrows P$). It is an inevitable result that appears simultaneously on a worldwide scale. Every revolution repeats, at a higher information density, the basic principle by which information asymmetry becomes power differentiation, and the results of power differentiation are fixed in still more concealed ways as the starting point for the next revolution.

Together, the three evolutionary directions constitute a self-reinforcing evolutionary cycle: every change in the form of information creates conditions under which power can become more concealed, and every concealment of power in turn accumulates momentum for the next deepening of information asymmetry.

Table 2 Comparison of the Five Revolutions

Table 2. Comparison of the five technological revolutions

Revolutionary stage	Core information type	T dimension: key technologies	I dimension: information-control mode	P dimension: typical forms of inequality
Agricultural Revolution	Biological information-Climate knowledge	Crop domesticationIrrigation	LandMonopoly over agricultural knowledge	Differences in ethnic groups' possession of resources
First Industrial Revolution	Mechanical principles-Thermal power	Steam engineTextile machinery	Industrial capitalMachinery and equipment	Colonial plunderClass differentiation
Second Industrial Revolution	ElectricityChemical industryManagement science	GeneratorInternal combustion engine	Technical standardsEnterprise organization	Capital exportImperialism
Information Revolution	DataNetworksSoftware	ComputersInternet	PlatformsIntellectual property rightsTraffic	Digital divideProducer–consumer inequality
Artificial Intelligence Revolution	AlgorithmsComputing powerHigh-quality data	Deep learningLarge models	Intelligent modelsData hegemony	Data colonialismAlgorithmic hegemony-Globalization of skill gaps

From the shared laws and the era-specific heterogeneity discussed above, one can distill the general logic by which technological revolutions affect social structure: technological leaders use information asymmetry to transform technological advantages into long-term institutional power, thereby enabling them to create and consolidate a "center–periphery" pattern on a global scale. This therefore raises more fundamental questions: how have Western developed countries systematically constructed and maintained their advantages, and why have developing countries fallen into the predicament of dependent development?

3 Tracing the Origins of Global Inequality under the TIP Framework

The TIP framework applies to social inequality in any era, and it is also applicable to differences in group resources during the Agricultural Revolution. However, after the Industrial Revolution, Western developed countries used technological monopolies and information asymmetry to establish a clear center-foreign-dependency structure in the world. Although inequality existed during the Agricultural Revolution, no cross-continental, institutionalized global hierarchy had yet taken shape. Therefore, this paper sets the starting point of its analysis at the Industrial Revolution and proceeds along the three dimensions of the TIP framework.

3.1 The T Dimension: The Formation, Blockade, and Intergenerational Lock-in of Technological Advantage

3.1.1 The Establishment and Maintenance of Technological Barriers In successive scientific and technological revolutions, the West has always been the first to achieve breakthroughs in key technologies, while also preventing late-developing countries from acquiring equivalent technological capabilities. Thus, the material starting point established by the West was itself the starting point of global inequality. Britain promulgated its patent law in 1624. From the eighteenth to the nineteenth century onward, it prohibited the export of textile machinery and the emigration of skilled artisans. Thereafter, until 1825, Britain repeatedly revised and strengthened this prohibition, expanding the restricted objects from the original textile machinery and iron-smelting equipment to a broader range of core technologies. The direct consequence of this blockade policy was that France, even into the 1820s, still relied heavily on British technicians and equipment imported from abroad; the mechanization of its textile industry lagged behind Britain by thirty years. Technological blockade was not accomplished through a single decree. It consisted jointly of three elements: patent law—the Statute of Monopolies of 1624—export bans, and restrictions on artisan emigration, forming a complete system of technological barriers.[28] After World War II, the United States led the creation of the *Agreement on Trade-Related Aspects of Intellectual Property Rights* (TRIPS), elevating technological blockade to the level of a multilateral institution. Technological barriers have always been the first solid screen through which core countries maintain their advantages.

3.1.2 Breaking Blockades and Information-Substitution Paths Technological blockade cannot completely prevent the progress of late-developing countries. Such countries will always use various information channels—labor mobility, reverse engineering, industrial espionage, and the like—to break through blockades. The beginning of the American textile industry was the result of Slater bringing the design of Arkwright' s spinning machine out of Britain to Rhode Island, while Germany' s nineteenth-century industrial catch-up also relied on systematic reverse engineering and intelligence networks of overseas students.[29] Although Britain' s technological blockade could effectively slow the pace at which late-developing countries caught up, it was not unbreakable. Slater was originally an apprentice at a textile mill in Derbyshire, England, and he had mastered all the design, operation, and maintenance knowledge of Arkwright' s spinning machine. In 1789, he used his own memory to bring all of this technical information to the United States. At the time, British customs prohibited textile drawings and technical materials from leaving the country, but it could not search a person' s brain.[30]

3.1.3 Information Advantage Creates an Upper Limit to Catch-up, Namely Technological Intergenerational Lock-in The technological barriers that late-developing countries break through are technologies controlled by the previous generation; this is the main cause of intergenerational lock-in. When late-developing countries began to use steam power and mechanical manufacturing, the forerunners had already created competitive rules around internal combustion engines, electricity, and scientific management. When late-developing countries were catching up with industrialization, the information revolution once again redefined the frontier of productivity through chips and software. Beginning in 2022, the United States adopted restrictive measures on the export of high-end AI chips to China.[31] It then expanded the scope of control several times in 2023 and 2024, placing more chip models and Chinese enterprises on the prohibited list.[32] However, these banned chips did not completely block China' s path to obtaining restricted chips. Chinese enterprises used data centers established in Malaysia and, through computing-power leasing routed via Indonesian telecommunications providers, indirectly obtained high-end Nvidia chips. Yet all of the chips obtained through these detours were the "previous generation" or "current [[unclear: text continues beyond the visible page]]

"previous-generation" products[33]. At the same time, the U.S. Department of Commerce, together with allied countries, is studying how to impose stricter controls on next-generation AI chip technologies—namely chip-design software, advanced process technologies, quantum computing, and so forth[34]. It can thus be seen that, in order to obtain the money spent on the chips currently under restriction, latecomers have already had next-generation chip technologies sealed off by the pioneers.

3.2 | Dimension: The Manufacture, Reinforcement, and Cognitive Capture of Intelligence Asymmetry

Only when technological advantage is transformed into information control can it be durably transformed into power. Through multiple mechanisms, the West manufactures and maintains intelligence asymmetry on a global scale. These mechanisms exist not only at the explicit institutional level, but also penetrate into the deep structures of intelligence value chains and cognitive frameworks.

3.2.1 Interception of the Intelligence Value Chain

Intelligence is by no means raw data; rather, it is decision-making knowledge obtained after successive layers of processing through collection, cleaning, integration, analysis, and assessment. Therefore, the high-value-added links in the value chain are always concentrated in central countries, while late-developing countries are intercepted at the nodes of data provision and low-end processing (as shown in Figure 4). The extreme ultraviolet (EUV) lithography machines produced by the Dutch company ASML are necessary equipment for manufacturing advanced chips. Yet buyers cannot fully "own" such machines[35]. **Operational knowledge is intercepted**: ASML requires that all EUV lithography machines be connected to its remote monitoring system located at its headquarters in the Netherlands, and any unauthorized disassembly or operation will trigger an alarm. The machine's core parameters, maintenance cycles, and fault diagnosis are all remotely controlled by ASML. In effect, purchasers are "renting" ASML's knowledge rather than buying the complete technology[36]. All advanced chip manufacturers worldwide must follow the technological tempo defined by ASML, because they cannot bypass ASML's lithography machines to produce advanced chips. The essence of value-chain interception can be summarized as follows: late-developing actors provide manufacturing and data, but cannot enter the links of defining standards, designing algorithms, or assessing trends.

Figure 4. Interception of the intelligence value chain

Flowchart text:

- **Foreign-country locked zone**
  - **Raw data collection**
    Free Internet in Africa · data extraction by transnational platforms
  - **Data cleaning and storage**
    Cloud processing · controlled by central enterprises
- **Interception point**
  - Intelligence-asymmetry interception point
- **Central-country control zone**
  - **Data analysis and modeling**
    Algorithm training · trend assessment
  - **Standard definition and rule design**
    Technical standards · data-governance rules

– **Intelligence products and decision-making knowledge**
Market forecasting · credit scoring · policy recommendations

Fig.4 Value chain interception

Data colonialism is an extension of the original logic into the digital age[37]: transnational platforms collect massive amounts of user data from around the world and process them into high-value intelligence products, yet the countries from which the data originate can neither share the benefits thereby obtained nor retain autonomy over their digital representations. A number of "free Internet" projects in Africa are, in fact, premised on large-scale data capture and preference-shaping, thereby causing the outflow of data value chains and regulatory gaps[38]. This is therefore by no means merely resource plunder; it is, even more, a process of turning developing countries into "data cows" in the era of the digital economy—providing core raw materials while being excluded from the links of processing, pricing, and the like.

3.2.2 The Institutionalization of Information Asymmetry

The interception of the intelligence value chain reveals the economic manifestation of information advantage. But once information asymmetry arises, the advantaged party has both the incentive and the capacity to turn it into a lasting institutional arrangement. Institutionalization is achieved through the power to make rules: when technological pioneers hold the power to define technical standards, a temporarily existing information gap is fixed into legal and institutional barriers. Even if latecomers possess production capacity, they must still produce according to the standards set by the pioneers. During the 2G era, Europe' s GSM standard and the United States' CDMA standard respectively occupied their respective

blank regional markets, and the power to set standards had not yet been fully centralized. By the 3G era, relying on its patent control over the core CDMA technology, Qualcomm came to dominate the overall pattern of 3G standard-setting; mobile-phone manufacturers worldwide had to pay Qualcomm substantial patent royalties before they could produce 3G equipment. In the 4G era, the European-led LTE standard became the globally adopted standard, but the core patent pool was still controlled by Western firms such as Qualcomm, Nokia, and Ericsson.[39] During the 2G period, Chinese firms had almost no standard-essential patents. In the 3G period, China-led TD-SCDMA became one of the three international standards, but its degree of internationalization was not high. In the 4G period, Chinese firms began to participate in the formulation of LTE standards, but their share of core patents was still less than 10%.[39] The real turning point came in the 5G era: Chinese firms such as Huawei and ZTE contributed roughly 30% of 5G standard-essential patents and, for the first time, gained substantive speaking power in the field of communications standards.[39] Yet this breakthrough also demonstrates the tenacity of rule lock-in. From 2G to 5G, latecomers spent a full thirty years moving from the original "passive recipients of standards" to today' s "participants in standards." During this period, Western firms had already earned hundreds of billions in revenue through patent licensing for the first three generations of standards and invested that money into research on the next generation of standards; here, rule lock-in and intergenerational lock-in converge.

There are 13 root domain-name servers in the world, 10 of which are in the United States. Amazon AWS, Microsoft Azure, and Google Cloud together occupy the majority share of the global cloud-computing market. More than 90% of the world's advanced AI training chips are designed by NVIDIA.[40]-[41] Once data becomes a principal factor of production[42] and computing power becomes a principal productive force, dependence on infrastructure is no longer merely a technical issue; it becomes an issue of power. Rules determine the standards according to which production is carried out, while infrastructure determines what is actually produced. Together, the two transform information asymmetry from a market phenomenon into an institutional structure.

3.2.3 The Invisible Operation of Cognitive Power

At a deeper level, information asymmetry is cognitive power—that is, the authority to speak on such questions as "what counts as knowledge," "what counts as development," and "what counts as rational policy." Its real power therefore does not lie in direct coercion, but in using the academic evaluation system, international standard-setting, and the methods prescribed by development discourse to induce foreign countries automatically to accept the cognitive models of the central countries.

Inequality in academic language is a direct manifestation of cognitive power. A rigorous analysis by scholars of 48.72 million papers indexed in the Web of Science Core Collection from 1978 to 2023, together with 1,827 scholars from 52 countries, found that the average time cost for non-native English speakers to publish an SCI paper is 1.8 times that of native English speakers; over the past decade, the share of non-English papers in the database has continued to decline, from 11.2% to 6.7%. More importantly, 93.4% of the scholars interviewed believed that the current evaluation system constitutes a "substantive academic barrier" for them[43] (see Figure 5). Thus, knowledge production in foreign countries must not only participate in competition over academic quality, but must also overcome the structural disadvantage created by the language barrier: only when knowledge is translated into the academic language of the center can it receive genuine recognition.

Line chart labels: y-axis, "Share (%)" ; x-axis, "Year" ; legend, "Share of non-English papers (%)" ; data labels: 1980–12%, 1990–11%, 2000–10%, 2010–8.5%, 2020–7.2%, final point–6.7%.

Fig. 5 Changes in the share of non-English papers in the Web of Science Core Collection

Fig. 5 Share of non-English papers in WoS Core Collection

Similar structures are highly evident in the international knowledge order: top-tier academic journals, major patent databases, and the technical committees of international standards organizations are all dominated by a small number of Western countries. As a result, scholars in peripheral countries who wish to obtain cutting-edge scientific information have no choice but to subscribe to these databases; policymakers in peripheral countries who wish to participate in international trade likewise have no choice but to accept these standards. Access to knowledge itself has thus become a relation of power.

3.3 P Dimension: Institutional Nesting and Layering Effects in the Entrenchment of Power

Information asymmetry ultimately becomes entrenched, through mechanisms such as rule-making and resource redistribution, as a structural differentiation of power across the three levels of the state, society, and space. This process of entrenchment is not completed in a single step; rather, through institutional nesting and historical layering, it forms a composite structure that is difficult to dismantle.

3.3.1 Rule-Making and the Trap of Emergency Learning When informational advantage accumulates to the threshold at which rules can be formulated, power naturally leaps from the "quantitative advantage" possessed by market competitors to the "qualitative control" held by rule-makers. After Britain's first Industrial Revolution, the Vienna system and the gold standard served as vehicles through which industrial advantage was successfully converted into global trade rules. In a striking parallel, after the Second World War the United States used the Bretton Woods system, the International Monetary Fund, and the lending conditions of the World Bank as tools to solidify economic advantage into international financial discipline.

For late-developing countries, joining a rule system is in essence a compelled form of "emergency learning": institutions are not designed on the basis of the actual needs of their own development, but must instead accept the framework established by central countries in order to avoid being excluded. The "Brussels effect" of the EU's *General Data Protection Regulation* (GDPR) is a typical case: GDPR directly shaped the data-protection legislation of 18 non-EU countries[^44] (see Fig. 6), not because GDPR is a universally applicable gold standard for privacy protection, but because non-compliance would mean exclusion from the EU's large market. The total amount of fines has already reached US$1.3 billion[^45], and data restrictions in South Africa have led to a 9.1% decline in total output and a 3.7% decline in productivity[^46]. It can thus be seen that, in most cases, data-protection legislation in developing countries is passive compliance with rules set by the center.

Figure labels: vertical axis, "Cumulative number of non-EU countries adopting

GDPR-type legislation" ; horizontal axis, "Year" ; annotation, "GDPR officially came into effect in 2018." Point labels: 0, 1, 3, 5, 9, 13, 16, 18.

Figure 6. Diffusion trend of data protection legislation in non-EU countries

Fig. 6 Diffusion of data protection laws in non-EU countries

Late-developing countries signed TRIPS—the *Agreement on Trade-Related Aspects of Intellectual Property Rights*, a multilateral trade agreement under the framework of the World Trade Organization—not out of their own developmental needs, but because, in order to enter the global trading system, they had no choice but to accept established rules. If they accepted, the cost of acquiring technology would rise and they would lose autonomy; if they refused, they would be excluded from the global market and marginalized. Institutional change was passive and compelled, rather than autonomously designed. Thus, when late-developing countries accept the rules, they lose autonomy; when they reject the rules, they are marginalized.

3.3.2 Unequal Layered Superposition

From the perspective of temporal heterogeneity, the unequal forms associated with the five technological revolutions can be analyzed as follows: these forms do not replace one another, but instead accumulate layer upon layer, forming a composite structure (as shown in Figure 7).

The legacy of the colonial era has not disappeared. The trade-dependence relationships between former colonies and former metropoles, financial linkages with former metropoles, the one-way outflow of resources, and the institutional transplantation imposed on colonies remain important factors shaping the policy space of the latter. This constitutes the first layer of barriers, namely the colonial legacy (16th–20th centuries). The Bretton Woods system, IMF loan conditions, the SWIFT system, and passive debt governance have led to a second layer of barriers formed by international financial rules (1940s–). More importantly, the intellectual property regime (1990s–) has added a third layer of barriers on top of this structure: the costs developing countries must pay to obtain technical documents and the like are far higher than those borne by developed countries—for example, the TRIPS Agreement, restrictions on access to medicines, technology licensing fees, and so on.

The rise of digital platforms (2000s–) has added a fourth layer: asymmetries exist in both profit distribution along global value chains and data extraction. The popularization of algorithms (2020s–) has ultimately added a fifth layer at the very top: the allocation of opportunities, credit scoring, and information recommendation are all defined by algorithms from central countries, while peripheral countries are, in effect, passive recipients of algorithmic decision-making.

Figure 7 diagram text (top to bottom):

- Fifth layer
  Algorithms and intelligent control (2020s–)
  Opportunity allocation, credit scoring, information recommendation
- Fourth layer
  Digital-platform monopoly (2000s–)
  Data extraction, profit diversion
- Third layer
  Intellectual-property regime (1990s–)
  TRIPS Agreement, restricted access to medicines, technology-licensing fees
- Second layer
  International financial rules (1940s–)
  Bretton Woods system, IMF loan conditions, SWIFT system, passive debt governance
- First layer
  Colonial legacy (16th–20th centuries)
  Trade dependence, financial links with former suzerain states

Figure 7. Layered accumulation of inequality

Fig. 7. Layered accumulation of inequality

The crux of this layered structure is that late-developing countries can generally respond only to the pressure of one particular layer at a time, while the other layers continue to operate. Thus, even after intellectual-property barriers are dismantled, the problem of inequality in financial rules remains; after manufacturing efficiency is improved, difficulties arising from the one-way outflow of data inevitably appear. Catching up, therefore, is in essence a systematic demolition project with a definite sequence.

3.3.3 Vertical nesting of the micro-meso-macro levels

The center–periphery structure exists not only at the macro level among states, but is also nested within the micro and meso levels of individuals and organizations (as shown in Figure 8).

Figure 8 diagram text: Vertical nesting of power differentiation

- Micro level: individual skills and opportunities
  - Skills gap: India has 1.3 million AI learners; its proficiency ranking is 89th
  - Talent outflow: the United States concentrates 780,000 AI professionals; South Korea has only 57,000
  - Individual predicament: having the best ideas but being unable to use the most advanced tools
- Link between micro and meso levels:
  - Individual disparities accumulate upward
  - Platform and market structures amplify them

- Meso level: organizations and platforms
  - Platform monopoly: cross-border platforms extract data
  - Enterprise predicament: 90% of Nigeria' s DAPT services depend on cross-border tools
  - Value-chain interception: enterprises in developing countries are locked into low-end segments
- Link between meso and macro levels:
  - Organizational predicaments become solidified upward
  - Institutional rules constrain downward
- Macro level: international rule system
  - Rule lock-in: TRIPS Agreement, GDPR, IMF loan conditions
  - Value-chain distribution: Apple profits 58.4% vs. China assembly 1.8%
  - Cognitive power: barriers in academic discourse; power to set standards

Figure 8. Vertical nesting of power differentiation

Fig.8 Vertical nesting of power differentiation

At the micro level, the AI skills gap is creating new forms of individual inequality. In 2024, India had more than 1.3 million generative-AI learners, the highest number in the world; however, among 109 countries, it ranked only 89th in overall skill proficiency, and it is expected that by 2026 there will be a shortage of more than 1 million professionals in AI, machine learning, and data science.[47] The more fundamental problem is that growth in the number of learners does not necessarily lead to an improvement in intelligence capability: the high-end segments of the intelligence value chain are concentrated in a small number of institutions in a few countries. South Korea has approximately 57,000 AI professionals, the United Kingdom about 110,000, and the United States about 780,000,[48] showing that the global distribution of AI talent is extremely uneven. In Africa, AI developers face the same bottleneck. They have ideas, data, and coding ability, but they lack the computing-power infrastructure needed to train models. Advanced AI training chips are designed by Nvidia, while the three U.S. companies Amazon, Microsoft, and Google account for more than 60% of the global cloud-computing market; a small number of Western countries control computing-power infrastructure.[49] Computing power is the means of production in the AI era, and whether one can access advanced tools determines the conversion of individual innovators' achievements.

From the meso level, transnational platforms extract data and convert it into high-value intelligence products, while the countries from which the data originate and their users have almost no control rights in this value chain.

Free Basics, under the banner of "providing free Internet access to populations around the world who cannot get online," has been launched in dozens of countries across Asia, Africa, and Latin America, covering more than 60 countries worldwide and tens of millions of users. Through free access, Free Basics draws users into a digital ecosystem controlled by Meta, collecting at scale users' behavioral data, social relationships, location information, and content preferences. These data are transmitted in real time back to Meta' s servers in the United States; after analysis and modeling, they are converted into products for precision advertising, content-recommendation algorithms, and user profiling, creating tens of billions of dollars in advertising revenue for Meta each year[50]. Even when firms in developing countries become leaders in their domestic markets, it is extremely difficult for them to enter the high-value-added segments of global value chains. For example, 90% of the services of DAPT, a Nigerian data-compliance company, rely on cross-border data exchange or foreign-hosted digital tools. Its founder frankly stated: "I may have the best ideas, but if I cannot use the most advanced tools, I will be miles behind." Thus, this is a question of the right of access, not merely a question of technical capability. When infrastructure and key tools are controlled by central countries, the space for innovation among peripheral enterprises is systematically compressed. TCS is India' s largest IT services company, yet in the global IT value chain it has always been locked into the execution layer. Its core work is writing code, testing modules, and ensuring the stable operation of systems; however, the core architectural design that determines how this code is organized, how modules are divided, and how systems evolve is held by the clients. This lock-in is not because TCS lacks technical capability. TCS has one of the world's largest reserves of IT talent, invests hundreds of millions of dollars each year in research and development, and has accumulated substantial technical expertise in artificial intelligence, cloud computing, and blockchain. Yet in the global IT value chain, it has never defined an operating-system standard, never led the architecture of a core programming language, and never formulated a set of software-development specifications adopted worldwide. The power to set standards lies in the hands of Microsoft, Amazon, and Google; the power to design architectures lies in the hands of architects at clients' headquarters[51]. TCS merely proves that it "can deliver efficiently according to established standards," rather than that it can "create new standards." The enterprise possesses scale, talent, and technology, but it remains locked out of the high-value-added segments of the value chain, because the power to define standards, design architectures, and judge trends is not in its hands.

At the macro level, the ossification of the international rules system has already locked the various inequality mechanisms described above into institutions. Thus, the three levels reinforce one another: skill differences at the micro level are amplified by platforms and market structures at the meso level, while competitive disadvantages at the meso level are in turn locked into a persistent state by rules at the macro level. As a result, the lock-in effect discussed here emerges: a positive-feedback closed loop promotes the accumulation of advantages, and bistability makes it extremely difficult for initial differences to be reversed by the system' s own forces.

From the existing analysis, it can be seen that the center–periphery structure is a system with self-reinforcing capacity. Its dynamic characteristics can therefore be clearly summarized as a positive-feedback closed loop, threshold transitions, and bistability. This also leads to an extremely important cautionary conclusion: in the absence of effective external intervention, the artificial-intelligence revolution will not automatically dissolve global inequality; on the contrary, it will strengthen existing structures along two clear directions. First, with every step by which the level of intelligence increases, the entry threshold of information density rises accordingly, and the frequency of intergenerational lock-in accelerates from "one generation of technology, one generation of lock-in" to "one model generation, one instance of lock-in." Second, when algorithms are no longer tools but become infrastructure for the allocation of social opportunities, cognitive power extends from defining knowledge to defining people who are valuable. This is a more fundamental and more profound dimension of inequality than economic deprivation or institutional exclusion. Therefore, the real problem faced by late-developing countries is by no means the backwardness of a particular technology or institution, but rather the self-reproduction mechanism of the center–periphery structure as a systemic whole.

4 Conclusions and Outlook

4.1 Research Conclusions

Taking as its starting point the basic proposition in information science that "information reduces uncertainty and creates decision-making advantage," this paper derives the "technology–information

—power" (TIP) three-dimensional analytical framework, this article has conducted a historical comparative analysis of the agricultural revolution, the two industrial revolutions, the information revolution, and the artificial-intelligence revolution, and on this basis has systematically deconstructed the mechanisms by which global inequality is generated and consolidated. First, it constructs the TIP framework as a theoretical tool with clear disciplinary recognizability for analyzing the social impacts of scientific and technological revolutions: technological breakthroughs alter the information landscape; intelligence asymmetries are transformed into power advantages; and power, through rules, establishes and solidifies structural order. Second, successive scientific and technological revolutions all conform to the transmission laws summarized by the TIP framework, while inevitably bearing the heterogeneity of their respective eras; the form of power has already completed a paradigm shift from material control to intelligent control. Third, global inequality is, in essence, the result of technological forerunners creating and reinforcing the solidification of institutional power through systematic information asymmetry. New forms do not replace old forms; rather, they are superimposed upon them, thereby forming a compound structure with five accumulated layers: colonial legacies, financial rules, intellectual property rights, digital platforms, and algorithmic control.

4.2 Practical Implications

From the existing conclusions, this article can derive several strategic implications for late-developing countries in responding to a new round of scientific and technological revolution:

First, building intelligence capabilities is a prerequisite for breaking intergenerational lock-in. From the T dimension, simply importing technology cannot narrow the gap; countries must proactively build a national strategic science-and-technology intelligence system capable of foresight and of predicting the direction of shifts in technological paradigms, and make arrangements before the track changes. Second, entering the analytical and standards layers of the intelligence value chain is the key node for breaking dependency. From the I dimension, the breakthrough point for disrupting the existing pattern is not to perfect low-end segments, but to establish an endogenous capacity to transform raw information into decision-making knowledge, while also proactively participating in the formulation of international technical standards.

Third, the power to formulate technical standards and governance rules is the clearest and most typical landmark event in crossing the power threshold. From the P dimension, when late-developing countries pursue technological catch-up, they must not focus only on the technological gap itself; rather, they should more proactively seek windows for participation and leadership in every emerging technological field, from standard-setting to the formation of governance rules.

4.3 Research Limitations and Future Prospects

This article has several evident shortcomings:

First, empirical testing has not yet been fully developed, because the nonlinear dynamic characteristics discussed here are still at the stage of theoretical formalization. Subsequent research should explore, first, selecting a particular scientific and technological revolution—such as the First Industrial Revolution or the information revolution—for historical case process-tracing, so as to use qualitative methods to directly test the existence of positive-feedback closed loops and threshold transitions; and, where data conditions permit, establishing several model parameters for exploratory estimation. Second, the empirical identification of the power threshold Pth still requires fuller operationalization. Pth is a theoretical construct proposed in this article, with the acquisition of rule-making power as its empirical counterpart, and it should also be examined in specific historical contexts. Third, the boundary conditions of the framework remain to be explored. The TIP framework takes information as its basic analytical lens, explaining how scientific and technological revolutions trigger power restructuring by changing the information landscape; however, it cannot directly explain other sources of changes in power—such as military conquest, natural disasters, population migration, the independent evolution of ideology, and so forth—and it does not exhaust all causal pathways through which scientific and technological revolutions affect society. Therefore, future research should systematically compare the TIP framework from the perspectives of economics and sociology, thereby defining its explanatory increment and scope of applicability. Fourth, this article' s analysis of new forms of inequality in the era of artificial intelligence takes current technological trends as its point of departure; the capability boundaries of large models, data-governance institutions, and the evolutionary paths of such frontier technologies as brain–computer interfaces are all uncertain. Research on data colonialism, algorithmic hegemony, and the globalization of skill gaps should continue as a long-term research agenda. Fifth, this article has expanded international comparative research. Therefore, in the future it would be appropriate to apply the TIP framework to comparative analyses of specific country cases, thereby testing the framework' s applicability in explaining internal differentiation among late-developing countries and deriving more solid strat—

···implications.

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