Considerations on Scientific and Technological Innovation Empowering High-Quality Development of China's Industries (Postprint)

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Date: 2023-06-15T00:00:00+00:00

Abstract

The report of the 20th National Congress of the Communist Party of China identifies high-quality development as the primary task in comprehensively building a modern socialist country. Leveraging scientific and technological innovation to empower high-quality industrial development constitutes a crucial lever for promoting "new breakthroughs in high-quality economic development, significantly enhanced capabilities for self-reliance and self-improvement in science and technology, and major progress in constructing a new development pattern and modern economic system." This article systematically reviews the perspectives of frontline scientists and economists through the lenses of history and reality, theory and practice, and objectives and planning. It articulates the pivotal role of technological innovation in economic development and national strength enhancement, advocating for reduced resource consumption and an intensive development path. The article further proposes strategic shifts: from technological catch-up to establishing localized leading advantages, from end-product innovation to intermediate goods innovation, and from integrated innovation to original innovation. Additionally, it emphasizes exerting efforts across industry and technology sectors, establishing genuine market competition mechanisms at the micro level, and cultivating a technology culture oriented toward industrial technology.

Full Text

Several Thoughts on Empowering High-Quality Industrial Development in China Through Scientific and Technological Innovation

Historical Perspective: Technology as a Driver of National Power

Technology has repeatedly catalyzed "high-quality development" throughout history. If we liken "scientific discovery" to one side of a coin, the other side is "technological invention." The path from science to technology to industry is not a simple unidirectional derivation but rather a bidirectional interaction. Technological inventions are typically not derived from scientific principles alone but emerge from practice and the creativity of inventors, following their own distinct patterns and characteristics. Therefore, technological invention cannot merely wait for scientific discoveries to provide new concepts, ideas, or methods; it must develop in parallel with scientific discovery. Industry-focused technological innovation and invention deserve greater attention to truly realize science and technology as the "primary productive force" while simultaneously posing necessary questions to science that advance human civilization. Many innovations originate from industry and technically gifted engineers, with numerous historical lessons to draw upon. The example of steel technology illustrates the enormous driving force of technological invention and innovation on economic and social high-quality development.

Ancient Chinese Steel Technology: As early as the 7th–8th centuries BCE, Chinese people developed blast furnace iron smelting technology, which expanded its application during the Spring and Autumn and Warring States periods, rapidly boosting productivity and facilitating the formation and development of feudal society. Following the tumultuous Warring States era, this technology enhanced the overall national power of a unified state and laid a solid foundation for national strength. During the Han Dynasty, steelmaking technology improved further, directly strengthening military capabilities. Han armies wielded steel swords nearly one meter long, while Xiongnu forces lacked comparable weaponry and had to use inferior short bronze swords. Han forces also extensively employed iron arrowheads, which the Xiongnu could not mass-produce; their wooden arrows proved less lethal. This technological advantage in swords and crossbows created a combat ratio where one Han soldier could counter five or more Xiongnu warriors. Indeed, the Han Dynasty relied on advanced steel technology to augment its military power and effectively safeguard the security and stability of its agrarian society.

European Modern Steel Technology: Europeans only mastered blast furnace iron smelting in the 14th century, later developing coke-based iron smelting in the 18th century. Watt subsequently improved the steam engine, which was constructed from a mixture of wood and iron components requiring iron reinforcement. The large gaps between cylinders and pistons resulted in low ther-

mal efficiency. The 19th-century internal combustion engine demanded higher-quality materials and greater precision—requirements that wood, cast iron, and limited wrought iron could not satisfy. Until 1856, when Henry Bessemer invented the acid converter steelmaking process, Europe could not mass-produce cheap steel. In 1879, Sidney Thomas invented the basic converter process, further enhancing steelmaking capacity. Subsequently, the Siemens-Martin open-hearth furnace enabled Britain to achieve exponential steel production growth, becoming the world's leader and supporting its global hegemony. Germany later surpassed Britain in steel output by vigorously developing steel technology, emerging as an industrial powerhouse. By the early 20th century, American steel production exceeded Germany's, establishing the United States as a highly competitive industrial nation. Undoubtedly, steel technology served as a powerful instrument for Western powers seeking global dominance.

The Enterprise as Protagonist in Innovation: Comprehensive historical review reveals that disruptive inventions and major innovations in materials technology like steel have profoundly and enduringly impacted economic development and national defense capabilities. Inventors and engineers have made tangible contributions to global industrialization and modernization. In China, enterprises deserve greater recognition as the main actors in technological innovation to continuously enhance national competitiveness and secure future development advantages. Chinese enterprises should continuously increase their innovation content, striving for greater representation and higher rankings among the world's innovative technology companies. This represents an essential direction for China to resolve "chokepoint" issues and achieve technological self-reliance.

The Imperative of Technology-Driven Industrial Development

Since reform and opening up, China has completed high-speed industrial development through quantity catch-up, scale expansion, and factor-driven growth, becoming the world's largest manufacturing nation. However, further development has revealed urgent problems. First, while quantity gaps have been filled, quality gaps have become prominent. China is the only country possessing all industrial categories listed in the UN industrial classification system, with over 220 industrial products ranking first globally in output. Steel and cement production exceeds the combined total of all other nations, yet product quality and value-added levels require improvement. Second, the industrial system is large but not strong, broad but not deep, and comprehensive but not refined. Despite having all industrial categories, the system remains in the mid-to-low end of the value chain overall. Third, factor-driven growth has become unsustainable. Capital, labor, and other factor conditions and marginal outputs have changed—the production function itself has shifted—while resource and environmental constraints have intensified. It is no longer possible to drive economic growth primarily through factor inputs as in the past. Simultaneously, China's total factor productivity still lags significantly behind international ad-

vanced levels. Therefore, the transformation of industrial development models is imperative, and this "graceful turn" critically depends on scientific and technological innovation.

Industrial Development Laws: The current global wave of new technological revolution and industrial transformation is advancing rapidly. Industries cannot remain competitive without technology. From intelligent manufacturing and clean energy to biotechnology, new materials, and high-end equipment, disruptive technologies are emerging across all sectors, transforming industrial landscapes. The deep integration of intelligent technology with manufacturing has created intelligent manufacturing models, with "dark factories" and "unmanned workshops" on the rise. New technology-driven industrial transformations are fundamentally altering traditional manufacturing ecosystems—without technology, industrial transformation is impossible.

International Competitive Environment: From a global competitive perspective, the race for technological high ground has intensified into a "white-hot" stage. The United States is focused on "decoupling and breaking chains" with China in science and technology, with its "small yard, high fence" strategy centered on technology. The U.S. believes maintaining technological superiority will secure strategic competitive advantage over China. Consequently, America promotes "friend-shoring" and "near-shoring" in industrial supply chains to reduce China's role in global value chains and prevent China from occupying high-tech, high-value positions. This makes the strategic importance of accelerating scientific and technological innovation and achieving high-level technological self-reliance increasingly prominent for China.

China's Development Requirements: China has entered a new era of socialism with Chinese characteristics, marching toward the great rejuvenation of the Chinese nation through Chinese-style modernization. On March 13, 2023, President Xi Jinping stated at the First Session of the 14th National People's Congress, "On the new journey of building a strong country and achieving national rejuvenation, we must unswervingly promote high-quality development. We must fully, accurately, and comprehensively implement the new development philosophy, accelerate the construction of a new development pattern, deeply implement the strategies of invigorating the country through science and education, strengthening the country with talented personnel, and driving development through innovation, strive to enhance our capacity for self-reliance and self-improvement in science and technology, promote industrial transformation and upgrading, advance coordinated urban-rural and regional development, and promote green and low-carbon economic and social development to achieve effective improvement in quality and reasonable growth in quantity, continuously strengthening our country's economic, scientific and technological, and comprehensive national power." After more than 40 years of development since reform and opening up, China has shifted from "following" to "running alongside" and even "leading" in an increasing number of scientific and technological fields, yet shortcomings remain prominent. Weak basic research, insufficient

original innovation capability, dependence on others for key core technologies, and inadequate incentive mechanisms for scientific and technological talent all require urgent remediation to support Chinese-style modernization.

Strategic Recommendations for Integrating Innovation with Industrial Development

To better integrate high-quality industrial development with scientific and technological innovation, three key approaches are recommended:

Strategic Level: From Technology Catch-up to Building Localized Leading Advantages

Since reform and opening up, China has primarily adopted an "introduction-digestion-absorption-re-innovation" model for industrial technology development, emphasizing integrated innovation—in essence, "following." Now, as the U.S. seeks to "decouple and break chains" and "cut off" China, this blocks China's catch-up path, forcing China to build its own advantages in key areas. In the short term, comprehensive leadership is unattainable; achieving systematic transcendence still requires comprehensive innovation across the education system and other domains. Under these circumstances, China can select fields with relatively strong scientific and technological foundations—such as bridge and tunnel engineering, heavy machinery, clean energy, 5G communications, artificial intelligence, quantum communications, and advanced computing—to maintain and pursue localized leadership and establish asymmetric countermeasures.

Technical Level: From Terminal Product Integration to Intermediate Goods Innovation

In the past, Chinese industries focused primarily on terminal product integration innovation. For example, the Hualong One nuclear power unit, million-kilowatt ultra-supercritical thermal power units, million-kilowatt hydro turbines, high-speed rail, construction machinery, and communication equipment have achieved global competitiveness. However, many key components, devices, basic materials, and industrial software within these terminal products remain weak links with high import dependence. Compared to terminal products, these intermediate goods involve higher technological content and faster product iteration, requiring not only technical innovation but also commercial viability. Even when technological breakthroughs occur, intermediate goods without competitive cost-performance ratios cannot capture markets. With many Chinese terminal products already globally competitive, focusing on intermediate goods innovation has become urgent.

Policy Level: From Encouraging Integrated Innovation to Encouraging Original Innovation

Both building localized leading advantages and innovating intermediate goods require breakthroughs in key core technologies supported by basic research and original innovation capabilities. The 20th Party Congress report stated, "Edu-

cation, science and technology, and human resources are the foundational and strategic pillars for building a modern socialist country." Better coordination of education, science and technology, and human resources is needed to "advance as an integrated whole," creating new advantages in scientific and technological innovation through synergistic coordination and systematic integration. Effective implementation of supporting policies, particularly talent policies, is crucial for realizing innovation-driven industrial development.

Learning from China's Own Successful Experiences

The most practical approach to building an innovation system and institutional mechanisms that support high-quality development is learning from China's own advanced successful experiences. China's greatest advantage is its unified large market, whose scale enables bottom-up innovation mechanisms. For instance, Shenzhen initially had neither universities nor research institutes, yet its high-tech industry has developed the fastest since reform and opening up. Moreover, China has already entered uncharted territory, with successful "from 0 to 1" innovations:

Songshan Lake Materials Laboratory: Led by the Institute of Physics of the Chinese Academy of Sciences, guided by the Guangdong Provincial Department of Science and Technology, and co-built by the Dongguan Municipal Government and the Institute of High Energy Physics of the Chinese Academy of Sciences, the Songshan Lake Materials Laboratory has officially operated for five years. Its goal is to become an internationally influential new materials R&D base in southern China, an important component of national material science research, and a new window for Guangdong-Hong Kong-Macao cross-disciplinary openness. The laboratory features four core sectors: frontier scientific research, public technology platforms and large scientific facilities, an innovation prototype factory, and a Guangdong-Hong Kong-Macao cross-disciplinary science center, dedicated to exploring a full-chain innovation model from "frontier basic research → applied basic research → industrial technology research → industrial transformation." The path forged by the Songshan Lake Materials Laboratory represents a typical institutional mechanism reform—deriving continuous reform momentum from ongoing demand-supply exchanges and mutual advancement between Dongguan's enterprises and the laboratory, as well as from China's broader economic development trends.

China's Photovoltaic Industry: China commands 80% of the global photovoltaic module market, with photovoltaic electronic efficiency at 26% approaching theoretical limits and leading the world. This field is led by Chinese pioneers without foreign technology supply, representing a "from 0 to 1" innovation. These successful innovations involved numerous institutional and mechanism reforms, such as government subsidies and multi-faceted support for the photovoltaic industry, as well as optimized domestic and international competition.

Low-Carbon Intensification: Over the past decade, Chinese wallets have

gradually "stopped carrying cash"—a single mobile phone enables "traveling the world," plus navigation and other functions, making travel low-carbon, convenient, and comfortable. Mobile phones exemplify functional integration and resource reduction through technological innovation. Over 20 years ago, Chinese researchers traveling abroad had to carry bulky equipment and materials; now everything is "integrated into a mobile phone." Mobile payment QR codes, bike-sharing, and online shopping are innovations China has provided to the world. Similarly, Shanghai's Yangshan Phase IV automated terminal, the world's largest automated container port, empowers modern logistics through intelligent and digital technology, achieving low-carbon intensive development that drastically reduces manual labor while improving operational efficiency. Its loading/unloading, transportation, and production management control systems all use independently developed Chinese intelligent systems, truly equipping "Made in China" with a "Chinese chip." These domestic success stories demonstrate innovative institutional mechanisms that continuously generate resource-saving, intensive development initiatives worthy of repeated reflection.

The Critical Role of Enterprises

In the knowledge innovation system supporting high-quality development, universities, research institutions, and enterprises each bear distinct responsibilities, with enterprises as the key actors in the technological innovation system. Historically, China has treated enterprises as recipients of technology transfer rather than as research units—a perception requiring urgent change. Enterprises should not be understood merely as "production workshops" but as the main body of the innovation system. The focus of institutional design for innovation systems supporting high-quality development should be transforming past perceptions of enterprises.

The average R&D investment of China's top 500 enterprises is only 1.8% of total revenue, compared to nearly 4% for the world's top 500 companies—a significant gap. R&D investment is crucial for achieving high-quality development, requiring both "quantity" and "quality." In China's research system, top talent such as academicians and "Distinguished Young Scholars" are concentrated in universities and national key laboratories, with few in enterprises. Enterprises still primarily employ technical personnel rather than research scientists.

Currently, China's talent flow remains largely unidirectional. In developed countries, two-way talent mobility between universities and enterprises is smooth, with professionals commonly returning to academia after working in industry. In China, such "reverse flow" remains rare. Future policies that provide more appropriate arrangements in professional title evaluation and other areas for those who "go to sea" (enter industry) and later return to research institutes or universities would greatly facilitate two-way talent mobility.

For most researchers in universities and research institutions, research only be-

comes truly meaningful when it manifests as marketable products and services. Therefore, establishing an industry technology-oriented scientific and technological culture is essential. In the information field, truly valuable results mostly emerge not from universities or research institutions but from enterprises. Transistors, integrated circuits, graphical interfaces, smartphones, and deep learning large models were all developed by companies. Chinese firms like Alibaba, Tencent, and Baidu also possess world-class research capabilities in cloud computing and artificial intelligence. Among the 72 Turing Award winners in computer science through 2022, 18 came from enterprises, and over one-third of university Turing laureates had industry work experience, while very few came from national laboratories. Enterprises are closest to the market, best understand market needs, and are most aware of "chokepoint" issues. In national science and technology programs related to high-quality economic development, enterprises should be the "question posers," as well as the primary "answer providers" and "evaluators," making such programs targeted and effective. Currently, universities and research institutes still largely "revolve around publications," and the orientation for researchers has not fundamentally changed. Only when researchers truly regard enterprises as the main body of technological innovation will high-quality development enter a virtuous cycle.

How Technological Innovation Drives High-Quality Economic Development

Since reform and opening up, China has actively integrated into the world economic system, leveraging its comparative advantages such as abundant labor to achieve long-term sustained high-speed growth, becoming the world's factory and one of the three core nodes in global industrial and supply chains—a major beneficiary of economic globalization. Unlike Western countries that leveraged capital and technological advantages, China became a primary beneficiary through the diligent labor of hundreds of millions of people. As China's economy develops and the international political and economic landscape evolves, the factor-driven growth model has become unsustainable, particularly as China's labor cost advantage diminishes. China's economy urgently needs to shift from factor-driven to innovation-driven high-quality development.

Specifically, technological innovation can promote high-quality economic development in four aspects:

Transforming Production Methods: Major technological innovations, particularly disruptive technological revolutions, fundamentally transform industrial structures, organizational forms, and product/service formats. Enterprises mastering new technologies are more likely to seize market opportunities and expand market share, while technologically lagging enterprises gradually exit the market, driving overall technological advancement and productivity improvements economy-wide. Technological innovation facilitates supply-side structural reform and economic transformation and upgrading.

Reshaping Demand-Side Reform: Technological innovation stimulates various demands, particularly consumption demand, helping shift China's economy toward a domestic demand-driven growth model and better satisfying people's aspirations for a better life. New technologies create new products and services that stimulate new consumption demands. Artificial intelligence technology can identify individual consumer preferences through big data for precision marketing, providing personalized products and services that better meet evolving consumer needs. Big data and AI also enable faster, better supply-demand matching, organically integrating supply and demand sides to promote healthy economic cycles.

Promoting Sustainable Development: Since reform and opening up, China's rapid economic growth has caused environmental pollution and damage. Guided by the new development philosophy, China's economy is changing its development model toward sustainable development. By developing and adopting new energy, materials, and environmental technologies, energy consumption, material consumption, and pollution can be effectively reduced during production and consumption, cutting carbon emissions and promoting green development for harmonious human-nature coexistence.

Enhancing International Competitiveness: During the past 40 years of economic globalization, China fully leveraged its abundant labor resources and improved enterprise technology and competitiveness through "introduction-digestion-absorption-re-innovation." Due to changes in the international political and economic situation, particularly U.S. "decoupling and breaking chains" in high-tech fields, China must achieve independent technological innovation to resolve "chokepoint" issues in key core technologies, move up the global value chain, enhance resilience in global industrial and supply chains, and safeguard China's economic security and development interests.

Issues Requiring Attention

While technological progress can greatly advance social productivity, four issues require attention when vigorously promoting technological innovation:

Displaced Industries: Technological progress creates new products and services, spawning new industries and labor demand, while inevitably replacing labor in some industries. This is an inevitable result of technological progress and an important marker of economic and social advancement. However, we must protect the labor rights of workers in displaced industries, help them upgrade skills, secure new employment opportunities, and minimize shocks to labor markets and social stability.

Digital Divide: In the digital economy era, data has become a key production factor. The digital divide means industries and regions with abundant big data resources develop faster and gain larger shares of the national economy, while those with scarce data resources see their economic shares decline. Therefore, during digital technology innovation, government must play a role in narrowing

the digital divide, accelerating digitalization in lagging regions and industries to achieve common prosperity—a key component of high-quality development.

Proper Technology Use: We must regulate new technology use to ensure technology remains humane. While new technologies can improve efficiency and better satisfy consumer needs, inappropriate use may harm workers, consumers, and small and micro enterprises. For example, big data platform companies may use their technological advantages to practice price discrimination, collect and retain consumer personal information without compensation. While platforms provide flexible employment, they also fragment labor organization, placing workers in more vulnerable positions. Therefore, legal frameworks must ensure new technologies are used properly, making technology humane rather than cold-hearted and protecting the rights of vulnerable groups.

Market Mechanism Advantages: Promoting independent technological innovation, particularly major technological breakthroughs, requires leveraging institutional advantages in concentrating resources for major undertakings. Simultaneously, genuine market competition mechanisms must be established at the micro level to mobilize innovation enthusiasm among research institutions and market entities, select the most competitive micro-entities, and ensure the most efficient use of scarce resources. Independent technological innovation itself must follow a high-quality development path.

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Note: Figure translations are in progress. See original paper for figures.