Building an Independent National Science and Technology Innovation System: France' s Path to Becoming a World Science and Technology Power (Postprint)

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Abstract

Following the conclusion of World War II, General Charles de Gaulle set about establishing a series of national research institutions, endeavoring to construct an independent and autonomous scientific and technological innovation system while continuously implementing top-level design for national innovation strategy. These initiatives made an indelible contribution to France' s subsequent realization of the "Trente Glorieuses" (1960s-1980s) in science, technology, and high-tech industries, as well as its emergence as a contemporary global powerhouse in economic, military, and scientific-technological innovation. This article takes the end of World War II as its starting point, focusing on eight key aspects—establishment of national research institutions, construction of national scientific and technological innovation system, talent cultivation, basic research, research environment construction, achievement transfer and transformation, scientific and technological evaluation, and strategic layout of national innovation—to elucidate the primary pathways through which France built itself into a scientific and technological powerhouse.

Full Text

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As one of the world's leading scientific and technological powers, France boasts a long-standing research tradition and has achieved remarkable discoveries in fundamental research fields such as mathematics, physics, chemistry, and physiology or medicine, establishing itself as a major global scientific center. Following World War II, General Charles de Gaulle actively established national research institutions centered on national defense security and state will, striving to build an independent scientific and technological innovation system. These efforts enabled France to achieve its "brilliant three decades" from the 1960s to the 1980s. Whether measured by the number of Nobel Prizes and Fields Medals in natural sciences, scientific publications, patent applications, or the market share of high-tech products in aerospace, military manufacturing, high-speed rail, precision instruments, agricultural equipment, biopharmaceuticals, nuclear energy, and automotive industries, France has consistently maintained its status as a world science and technology power in the post-war era.

This article takes the end of World War II as its starting point and examines France's primary pathways to building a scientific and technological power across eight dimensions: the establishment of national research institutions, construction of the national scientific and technological innovation system, talent cultivation, basic research, research environment development, achievement transformation, science and technology evaluation, and national innovation strategy planning.

Establishing Comprehensive and Rationally Distributed National Research Institutions

As a typical centralized state, France in the 1930s–1940s, particularly after World War II, saw General de Gaulle recognize that developing science and technology was essential not only for national reconstruction but also for enhancing comprehensive national strength and international competitiveness. Centered on national defense security and socio-economic development strategies, the French government established a series of national research institutions within less than a decade. These included the National Center for Scientific Research (CNRS, 1939), French Institute of Petroleum (IFP, 1944), National Center for Telecommunications Studies (CNET, 1944), Atomic Energy Commission (CEA, 1945), National Institute for Demographic Studies (INED, 1945), National Institute for Agricultural Research (INRA, 1946), and National Office for Aerospace Studies and Research (ONERA, 1946), followed later by the National Center for Space Studies (CNES, 1961), National Institute of Health and Medical Research (INSERM, 1964), National Institute for Research in Computer Science and Automation (INRIA, 1967), and French Research Institute for Exploitation of the Sea (IFREMER, 1984). Although the Pasteur Institute (1887) and Curie Institute (1921) were not government-established, as public welfare research institutions, they received continuous government support and reliance. This top-level design enabled France to rapidly assemble a national research force covering key disciplines such as mathematics, chemistry, biology, materials sci-

ence, nuclear physics, life sciences, information and communications, aerospace, biotechnology, and marine energy development.

Building an Independent Scientific and Technological Innovation System

Continuously Adjusting and Improving the National Innovation System

France' s national scientific and technological innovation system is essentially a product of the post-war era. National research institutions created, reorganized, and expanded to serve national military development needs (1945–1957) launched the construction of France' s national research and innovation system. From 1958 to 1969, government-led technology promotion and achievement transformation involving national research institutions and state-owned enterprises fostered a collaborative innovation model among government, national research institutions, and state-owned enterprises. As large "private" enterprises (such as Matra) emerged as high-tech industry leaders, the French government promptly adjusted resources for scientific and technological R&D, granting certain status and funding support to "private" R&D enterprises. National research institutions subsequently began establishing cooperative relationships with such enterprises, and the government-national research institutions-state-owned enterprises- "private" enterprises model matured steadily (1970–1981). The optimization and improvement phase began in 1982 when national research institutions, through "co-construction and co-management" (with four-year contract cycles), created joint laboratories with higher education institutions for basic and applied research and collaborative laboratories with enterprises for applied and development research. In this collaborative innovation process, higher education institutions, particularly engineering schools, became incubators for cultivating talent needed by enterprises. Since then, the government-national research institutions-universities-enterprises (including state-owned and private) have initiated a national innovation system with distinct focuses, mutual complementarity, and coordinated development.

Classified Management Based on Institutional Nature and Positioning

France classifies its national research institutions into "science and technology type" and "industry and trade type." Science and technology-type national research institutions serve as the main force for "non-directional comprehensive free exploration," supervised by relevant ministries and primarily undertaking frontier interdisciplinary research, basic research, and partial applied research across various disciplines. For instance, the National Center for Scientific Research is currently France' s largest science and technology-type national research institution and one of Europe' s largest, making significant contributions to French, European, and global scientific research, particularly long-term basic research, and high-level talent cultivation. Industry and trade-type national research institutions constitute the main force for "directional applied research,"

jointly supervised by multiple ministries. Focusing on achievement transformation and industrialization development trends, they concentrate on applied research, development research, and minimal basic research in "single" disciplines or fields. The current Atomic Energy and Alternative Energies Commission (formerly the Atomic Energy Commission), National Institute for Research in Computer Science and Automation, National Office for Aerospace Studies and Research, and National Center for Space Studies belong to this category.

Strengthening Government Leadership in Scientific Research

In the process of independently building and developing its scientific and technological innovation system, France has continuously optimized and adjusted government management departments based on new opportunities and challenges in domestic and international science and technology development, as well as changing roles of various innovation actors. For example, since establishing the French Research Foundation in 1901, France has successively created the National Defense Inventions Administration (1915), Center for Scientific Research Applications (1939), and Interministerial Committee for Coordinated Action in Research (1959), split and reorganized decision-making consultative bodies such as the High Council for Scientific Research (1954) and High Council for Research and Technology (1982), and reorganized decision-making management departments including the Ministry of Scientific Research (1959), Ministry of Industry and Research (1974), Ministry of Research and Technology (1981), Ministry of Research and Higher Education (1986), and Ministry of Higher Education, Research and Innovation (2017).

From the perspective of national innovation system architecture, after decades of unremitting efforts, France' s current national scientific and technological innovation system comprises five levels: decision-making, consultation, funding, execution, and evaluation [Figure 1: see original paper].

Cultivating High-Quality Scientific and Technological Talent

Ensuring Stability and Efficiency of the R&D Workforce

In 1981, the French government proposed the slogan "revitalizing science and technology to overcome crisis," emphasizing economic development through science and technology. The 1982 and 1985 "Orientation and Programming Law for Research and Technological Development" and "Law on Research and Technological Development" elevated scientific and technological R&D to national strategic heights and, for the first time, legally granted researchers national public servant status and benefits. Main measures included unified standard basic salaries, plus allowances and bonuses based on institutions and positions. Researchers could also request mobility between national research institutions (including universities) according to their professional development needs. During this process, their working environment and institution type might change, but their basic salary and benefits remained unchanged. In 2015, France had 417,100 full-time research and support personnel, including 266,700 full-time researchers. France' s researcher density (per thousand workers) reached 9.3.

Cultivating Talent Through Industry-Academia-Research Cooperation

Since the 1970s–1980s, while guiding society to foster a "craftsman" spirit and innovative mindset and creating a strong academic atmosphere, the French government has particularly focused on strengthening technical training for researchers according to market demands, aiming to cultivate young researchers capable of serving major national strategic tasks.

(1) **Establishing Research Allowance and Scholarship Training Programs**. In 1976, the French government funded research allowances. Excellent students were publicly selected from higher education institutions and funded through periodic training contracts to pursue doctoral degrees. A principle consistently maintained was the dynamic and rational allocation of research allowance funding ratios according to industry and disciplinary needs. A 1986 survey showed that among those funded in 1982, approximately 20% of young researchers entered national research institutions, higher education institutions, and R&D enterprises.

(2) **Implementing Industrial Research Training Programs**. As one of the talent cultivation bases, national research institutions also bear the responsibility of training high-level industrial researchers for R&D enterprises, particularly small and medium-sized enterprises. To this end, the French government introduced industrial research training programs, offering young engineers opportunities for further education through contract-based arrangements (typically three-year contracts). Unlike research allowance and scholarship programs, trainees in this program are entirely recommended by enterprises according to national disciplinary field selection quotas, with costs shared equally by government and enterprises during the training period.

(3) **Creating Engineer Technical Training Centers**. To promote enterprise transformation and upgrading amid scientific and technological development and changes, and to intensify training for engineers and other technical professionals, France created 25 engineer technical training centers nationwide from 1984 to 1987 based on regional advantages of research institutions and higher education institutions, with training cycles of 3–4 years. After each technical training center became operational, subsequent costs were jointly borne by the enterprises of participating trainees. All trainees were in-service high-level young researchers or technical personnel from industry-academia-research circles.

Emphasizing the Role of Basic Research with Continuous and Stable Support

Input Proportion

According to World Bank statistics on GDP, France' s GDP in 2016 was approximately US$2.47 trillion (current prices), ranking 6th globally. As shown

in [Figure 2: see original paper], from 2000 to 2015, France' s basic research expenditure as a percentage of GDP remained higher than other countries, continuously stable at around 0.5%. As shown in [Figure 3: see original paper], from 2007 to 2013, comparing the three types of R&D expenditure composition in the United States, Japan, and the United Kingdom, France' s investment proportion for basic research was also significantly higher than the other three countries. In 2013, France' s basic research expenditure was €11.516 billion, accounting for approximately 24.3% of total R&D expenditure; in 2014, it increased to €11.687 billion, accounting for approximately 24.4% of total R&D expenditure.

Output Effectiveness
According to 2017 statistics from the French Ministry of Higher Education, Research and Innovation, France ranked 7th globally in scientific publications and 4th in the European patent system in 2015 (accounting for 6.3% of applications). Since the establishment of the Nobel Prize in 1901, France has had 33 laureates in natural sciences, plus 12 Fields Medal recipients in mathematics. France' s remarkable achievements are inseparable from its long-term, continuous, and stable emphasis on basic research.

Legislatively Guaranteed Research Investment
The "Orientation and Programming Law for Research and Technological Development"clearly stipulated the proportion of national public research expenditure to GDP and its annual growth rate, requiring rational allocation of national funding proportions for basic, applied, and development research, as well as for major scientific and technological development priority areas according to contemporary disciplinary development needs. In 1985, building on experience from the 1982 science and technology legislation, the French government further mandated reasonable annual increases in research expenditure based on national economic conditions. For a long period thereafter, France' s total R&D expenditure as a percentage of GDP experienced some fluctuations but maintained steady growth thanks to national legislative guarantees, rising from 2.17% in 2010 to 2.23% (€48.6 billion) in 2015.

Creating a Favorable Research Environment and Relaxed Academic Atmosphere

Since the 21st century, actively cultivating and attracting global outstanding research and teaching talent has become one of the French government' s important means to revitalize and enhance the country' s original innovation and competitiveness in scientific and technological R&D.

Creating a Free and Competitive Academic Atmosphere
(1) **Abolishing Traditional Public Research Funding Allocation and Introducing Competition Mechanisms**. The establishment of the French National Research Agency (ANR) in 2005 represented a major reform. The French government strengthened top-level design, broke the original public re-

search funding allocation system, and mobilized the initiative of research units and researchers through merit-based, competitive approaches while simplifying research fund application and management procedures from top to bottom and expanding beneficiary groups. To strengthen scientific research freedom and openness, 25%–50% of ANR' s annual funded projects are unrestricted disciplinary field free-application projects, allowing researchers to freely choose research directions and objectives.

(2) **Integrating Higher Education and Scientific Research Strategies**. In 2013, the French government introduced the "Higher Education and Research Guidance Act," aiming to further promote international integration of higher education and drive the integration and transformation of higher education, scientific research, and technological innovation systems, facilitating the shift from elite education to universal education. This act provides legal guarantees and policy guidance for optimizing France' s current education system, university curriculum arrangements, and scholarship distribution, enhancing internationalization levels, and plays an important role in cultivating innovative talent, improving social adaptability of university graduates, and promoting innovation capacity across society.

Implementing Active International Exchange and Cooperation Policies

(1) **Conducting Diversified International Exchange and Cooperation**. Through targeted bilateral and multilateral international scientific and technological cooperation to further improve its own scientific and technological system, compensate for shortcomings in the technological value chain, and promote scientific and technological progress to enhance France' s global competitiveness and influence—this has been the core cornerstone of France' s foreign scientific and technological cooperation policy since the 1980s–1990s. To this end, the French government explicitly stipulates that "under all circumstances, international cooperation should follow the principle of continuity from upstream to downstream, beginning with academic exchanges, personnel training, and joint research, and concluding with technology transfer, industrial, and economic cooperation." Additionally, France has formulated matching scientific and technological cooperation strategies based on the scientific, technological, and economic development levels and disciplinary advantages of Western Europe, the United States, Japan, Eastern Europe, and third-world countries.

(2) **Creating an Open and Relaxed Research Environment**. On one hand, France implements diversified funded talent introduction programs, mainly including postdoctoral return plans, young researcher programs, and outstanding visiting professor programs. On the other hand, it encourages researchers to participate in scientific and technological cooperation around large-scale international research infrastructures. Large-scale infrastructures are important bases for attracting and cultivating outstanding talent, multidisciplinary integration, and achievement transformation.

While striving to attract foreign high-level researchers to France, France also encourages and supports domestic researchers to participate in EU large-scale scientific and technological cooperation programs, including the "European Community Research and Development Program," "European Galileo Program," "Sixth-Generation Ariane Rocket R&D Program," and "Microgravity Research Topics Program under ESA Framework."

Establishing an Effective Mechanism for Promoting Industrialization of Research Achievements

France's long-term position at the forefront of global industries such as aerospace, high-speed rail, nuclear energy, agriculture, pharmaceuticals, automotive, and precision machinery benefits from its long-standing emphasis on basic research alongside institutional mechanisms for transferring research achievements to industrialization.

Mechanism Integration

Driven by the national research and innovation strategy and adapting to the trend of multidisciplinary intersection in the global information technology revolution, the French government has reorganized the national research landscape to facilitate achievement transformation institutionally. Led by the National Research Agency, multiple scientific alliances have been established nationwide by field: the Life Sciences and Health Research Alliance, National Energy Research Coordination Alliance, Digital Science and Technology R&D Alliance, Environment R&D Alliance, and Humanities and Social Sciences Alliance. To maximize "chemical reactions"among R&D actors within each alliance, thematic research networks and thematic research centers have been established at the alliance level by discipline. For example, under the Life Sciences and Health Research Alliance, the medical thematic research network has established specialized research themes in audiovisual, cancer, neurology, infectious diseases, and premature birth.

Policy Guidance

The research tax credit policy, implemented by the French government since 1983, has been a consistent preferential policy aimed at encouraging enterprises to increase R&D investment and strengthen industrial innovation by reducing corporate taxes. Enterprises can enjoy research tax credit benefits for R&D investments that increase by more than 50% compared to the previous year. Without government intervention, enterprises can choose projects suitable for their own research and development based on their development needs and market prospect analysis and forecasting. In 2013, France introduced the innovation tax credit policy as an extension of the research tax credit policy, encouraging innovative research on new products in the prototype design, debugging, and trial stages, allowing a 20% tax credit on innovation research costs, capped at €400,000.

Fund Support

Focusing on uniting financial support institutions such as national banks, local banks, trust investment institutions, and state-owned consortia to establish efficient and stable funding chains to guide and promote industry-academia-research institutions in industrializing research achievements has been a long-standing guiding principle of the French government. Since the late 20th century, France has created diversified funds for aerospace, new energy, materials, biotechnology, and life sciences, such as the National Innovation Competition and Technology Research Fund (1999), Venture Capital Development Fund (2000), Interministerial Unified Fund (2006), National Patent Fund (2010), National Digital Society Fund (2013), and Intellectual Property Operations Fund (2013).

Salary Guarantees

To encourage closer ties between national research institutions and small and medium-sized enterprises, the French government has introduced two policies to guarantee researcher remuneration: (1) a leave-of-absence policy where researchers' positions at their original research units are retained when they enter enterprises, allowing them to return at any time; and (2) a reward and subsidy policy where SMEs can receive a one-time bonus from the state when hiring researchers. Once the employment contract is signed, the hiring enterprise receives 50% of the bonus, with the remaining 50% paid after the researcher has worked for one year.

Platform Construction

Diversified platforms are the most direct and effective means to promote achievement transformation and industrialization. Under national unified planning, by 2017 France had established 14 technology acceleration transformation companies, 72 Carnot Institutes, 171 Laboratories of Excellence, 8 Technology Research Institutes, and 71 Competitiveness Clusters as diversified transformation platforms or institutions. Competitiveness Clusters, for example, maximize the integration of industry-academia-research resources within specific geographic areas, driving coordinated regional innovation development through the free flow of talent, knowledge, technology, and capital. These 71 Competitiveness Clusters currently cover 14 industrial sectors including automotive, aerospace, agriculture, consumer goods, biological resources, life sciences, chemicals, energy, materials, micro-technology, optics, ecological technology, communications technology, and modern transportation.

Establishing an Evaluation System Aligned with National S&T Development Realities

Science and technology evaluation is the yardstick for measuring whether the scientific and technological innovation system and its actors operate efficiently around national needs and established strategic objectives. France' s scientific and technological innovation system construction and development has undergone a long period of reform and optimization.

Revising and Improving S&T Evaluation Legislation to Establish a Complete Set of Evaluation Indicators

Since the 1982 "Orientation and Programming Law for Research and Technological Development" mandated comprehensive periodic evaluation of researchers, teams, programs, and achievements, France' s science and technology legislation has undergone two major revisions and improvements: (1) On the basis of consolidating and refining the 1982 S&T evaluation act, the 1985 "Law on Research and Technological Development" formally emphasized the status and role of S&T evaluation in articles, standardized evaluation workflows, and required evaluation authorities to conduct regular comprehensive evaluations of large scientific research projects or programs and large scientific research institutions, particularly national research institutions. (2) The 2013 "Higher Education and Research Guidance Act" made the greatest improvement by integrating France' s higher education system and innovation research system into one, adopting different indicator systems and evaluation rules for different innovation units such as thematic research units, interdisciplinary research units, national research institutions, higher education institutions, and government agencies.

Adjusting S&T Evaluation Agencies to Achieve Openness, Transparency, and Efficiency

Peer review has been the evaluation method consistently adopted by French official S&T evaluation agencies. Since 1982, the French government has established five S&T evaluation agencies: the National Committee for Scientific Research (CoNRS), National Evaluation Committee (CNE), National Committee for Scientific Research Evaluation (CNER), Agency for Evaluation of Research and Higher Education (AERES), and High Council for Evaluation of Research and Higher Education (HCERES). After continuous experimentation and practice, only the "National Committee for Scientific Research" and "High Council for Evaluation of Research and Higher Education" remain operational. The former primarily conducts internal evaluations of researchers, research projects, thematic research institutes, and research units at the French National Center for Scientific Research, while the latter is mainly responsible for external evaluations of various higher education institutions, research institutions (including laboratories and research units), and large-scale scientific planning projects.

Formulating New-Period Innovation Development Strategies to Maintain France' s Innovative Edge

Resolutely Adjusting National Innovation Development Layout

To address major global challenges in science, technology, and environment, and to maintain France' s status as a world-class scientific and technological power, the French government promulgated and implemented the "France–Europe 2020" strategy in 2015, becoming the second national scientific research and innovation development strategy following the "National Research and Innovation Strategy (2009–2013)." This strategy aims to provide decision-making support for France at the macro level on major issues such as climate change, sustainable

development, and energy structure adjustment. Based on further improving the national strategic planning process and coordination mechanisms, it vigorously promotes technological research in key areas, constructs digital infrastructure and training facilities, and promotes the implementation of new transformation policies. Focusing on the strategic layout of national innovation development in the new period, the French National Research Agency and industry-academia-research institutions concentrate on innovative research in fields such as clean energy, life and health, food safety, sustainable transportation, information and communications, space development, and citizen security.

Implementing a New Round of "Investments for the Future"
Through issuing national bonds, €35 billion was injected into the Intellectual Property Operations Fund, National Digital Society Fund, Start-up Credit and Innovation Start-up Credit, among others, focusing on funding five modules: higher education and training (€11 billion), innovative research (€7.9 billion), industry and SMEs (€6.5 billion), sustainable development (€5.1 billion), and digital information industry (€4.5 billion). The "Investments for the Future" program consists of two sub-programs: non-tender special plans and competitive tender plans. The former focuses on applied and development research in aerospace (Ariane series rockets), aircraft manufacturing (Airbus series), and nuclear energy through directed funding, with funds directly allocated to project implementation agencies. The latter primarily involves the Ministry of Higher Education, Research and Innovation drafting tender documents, which are discussed at interministerial meetings chaired by the French Prime Minister, with project selection organized by the National Research Agency, focusing mainly on fields where France has traditional advantages such as biotechnology, energy, nanotechnology, and life sciences.

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