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The Fragmented Dilemma and Optimization of China's Natural Gas Technology Innovation from a Policy Portfolio Perspective: A Quantitative Analysis Based on 189 Policy Documents

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ABSTRACT

As a key transitional energy source for achieving the "dual carbon" goals, the scientific and technological innovation capacity of the natural gas sector directly impacts China's energy security and industrial structure transformation. Based on 189 natural gas science and technology innovation policy documents issued by central and local authorities between 1978 and 2025, this study constructs a three-dimensional analytical framework encompassing "objectives – tools – actors" and employs content analysis and social network analysis methods to quantitatively deconstruct the structural characteristics of the policy system. The research reveals that China's natural gas science and technology innovation policies exhibit a distinct "triple disjunction" pattern: in terms of objectives, policy support for increasing upstream reserves and production is severely inadequate; in terms of tools, rigid constraint instruments such as measures and regulations account for less than 9%, creating a "soft constraint" dilemma; in terms of actors, cross-sectoral coordination is highly concentrated among a small number of core departments under the National Development and Reform Commission, resulting in a pattern of "formal coordination but substantive isolation." The root cause of this fragmentation lies in the compartmentalized administrative system, policy volatility driven by short-term political agendas, and an assessment and incentive mechanism that tends to "avoid addressing critical issues." These three dimensions reinforce each other, forming structural barriers that constrain innovation efficiency.

KEYWORDS

Natural Gas Technological Innovation; Policy Mix; Fragmentation; Policy Text Analysis; Collaborative Governance.

1. INTRODUCTION

1.1. Research Background

As a low-carbon, clean fossil energy source, natural gas plays a pivotal role in safeguarding China's energy supply security and advancing the implementation of its "dual carbon" goals. In recent years, China's dependence on imported natural gas has been steadily increasing; consequently, exploration and development activities in deep-earth, deep-sea, and unconventional gas and oil sectors have become the primary front for expanding reserves and boosting production, creating an increasingly urgent need for scientific and technological innovation. In 2016, the National Development and Reform Commission and the National Energy Administration jointly issued the "Energy Technology

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Revolution Innovation Action Plan (2016-2030)," which identified the development of unconventional oil and gas resources, as well as deep-earth and deep-sea oil and gas resources, as one of 15 key tasks. The "14th Five-Year Plan for a Modern Energy System," released in 2022, further emphasized the need to strengthen China's competitive edge in energy innovation. In 2025, the National Energy Administration and other relevant departments issued the "Guiding Opinions on Promoting the High-Quality Development of Energy Equipment," focusing on advancing oil and gas equipment technology in fields such as deep-earth exploration at depths of 10,000 meters and deep-sea operations at depths of 1,000 meters.

According to statistics, between 1978 and 2025, the central and local governments have jointly issued 189 policies related to natural gas science and technology innovation; particularly after 2018, the number of such policies entered a phase of rapid growth. However, the continuous increase in the number of policies has not kept pace with breakthroughs in core technologies; the quantitative expansion of the policy framework has not yet been effectively translated into a qualitative leap in technological innovation.

1.2. Research Meaning

This study integrates portfolio policy theory and collaborative governance theory into the analysis of natural gas science and technology innovation policies, establishing a three-dimensional "goal-tool-actor" analytical framework to provide a practical analytical tool for the structured evaluation of energy policies. Through a quantitative decomposition of 189 policy documents, this study further identifies structural weaknesses within policy systems, thereby offering a basis for optimizing the supply of natural gas science and technology policies and enhancing the overall effectiveness of the innovation system.

1.3. Research Methods and Data Sources

This study employs content analysis and social network analysis methodologies. The policy text data were sourced from the Peking University Legal Information Database, the official websites of governments at all levels, and departmental gazettes, covering the period from 1978 to 2025. A total of over 1,700 relevant policy documents pertaining to the natural gas sector were identified through initial database searches. A multi-layered keyword screening system was developed around the theme of "Natural Gas Science and Technology Innovation"; through manual review, policies with low relevance were excluded, resulting in the extraction of 189 valid policy samples. Among these, 83 samples were at the central government level (comprising 55 standalone documents and 28 joint documents), and 106 samples were at the local government level.

2. THEORETICAL BASIS AND LITERATURE REVIEW

2.1. Theoretical Principle

1) Policy Portfolio Theory

The policy mix theory refers to a systematic framework in which the government employs a variety of policy instruments in a coordinated manner to achieve multiple objectives. This theory originated from addressing issues of both domestic and international economic equilibrium; it was initially developed by Mid and Mundell, who advocated for the rational combination of fiscal and monetary policies to coordinate the domestic economy with the balance of payments. Flanagan et al. argued that the "consistency" and "coherence" of the policy mix are key variables influencing innovation performance; an imbalance among mandatory, incentive-based, and voluntary policy instruments can lead to a reduction in policy effectiveness [1].

2) Synergistic Governance Theory

Synergistic governance theory is an interdisciplinary framework that integrates synergetics with governance theory; it represents a management approach emphasizing multi-stakeholder collaboration, with its core principle being the resolution of public issues through consultation and consensus among various actors-such as the government, the market, and society. The synergistic governance analysis framework proposed by Emerson et al. demonstrates that effective cross-sectoral collaboration requires the dual support of "shared motivation" and "joint action capacity" [2].

2.2. Literature Review

1) Research on Natural Gas Technology Innovation

Research on technological innovation in the natural gas industry has given rise to a multitude of significant themes. In the area of integrating technological innovation with standards, Zhou Li et al. conducted an in-depth analysis of China's technological innovation and standard-setting policies, delineated a pathway for integrating technological innovation and standards in the natural gas sector, and developed an integrated development model [3]; Miao Qing , drawing upon the talent ecosystem theory and the innovation value chain perspective, constructed a three-dimensional cultivation mechanism model encompassing selection, motivation, and development, and argued that establishing appropriate selection, motivation, and development mechanisms can effectively enhance the innovative capacity of young scientific and technological talents [4]; Regarding green development pathways, Gu Sui et al.summarized the essence of a strategic green development pathway for natural gas technological innovation and subsequently outlined the implementation process-comprising strategic planning, strategic implementation, and strategic evaluation [5]. Additionally, some studies focus on the institutional environment and policy synergy surrounding technological innovation; Yu Cuiting et al. performed a quantitative analysis of national-level natural gas industry policy texts spanning the period 2004-2022, revealing that administrative and technical measures are widely employed, whereas the synergy between financial measures and other economic measures requires further enhancement [6].

2) Research Review

Existing research has explored natural gas science and technology innovation from various dimensions - such as technological R&D, talent development, standard-setting, and policy coordination - yet much of this work evaluates energy policies from a single perspective, either focusing on the effectiveness of policy instruments or on the extent to which policy objectives are met, while lacking a systematic diagnosis of the internal structure of the policy system. Building on this, this paper conducts an in-depth analysis of China's natural gas science and technology innovation policies across three major dimensions - policy objectives, policy instruments, and policy actors - identifies the core challenges within the current natural gas science and technology innovation policy framework, and proposes actionable recommendations based on these findings.

3. THE "TRIPLE DISRUPTION" IN THE POLICY MIX

3.1. Target Dimension: Policy Supply Gap between Upstream and Downstream Sectors

1) Downstream guidance-based target distribution pattern

Table 1 presents the phased statistical breakdown of the four categories of policy objectives for the period 1978-2025. In terms of total number, the distribution of these four policy categories exhibits a significant degree of imbalance: the number of downstream-oriented "promoting utilization" policies is 2.26 times greater than that of upstream-oriented "accelerating development" policies. Even when

the "accelerating development" and "ensuring supply" policies - which directly support upstream resource reserve expansion and production growth, as well as the development of midstream storage and transportation systems - are combined for statistical analysis, their total number remains lower than that of the "promoting utilization" policies. This data distribution reveals an important phenomenon: policymakers generally place a greater emphasis on downstream markets than on upstream resource replacement.

Table 1. Phased Statistical Breakdown by Policy Objective Type

target / a particular year	Accelerate natural gas development	Ensure natural gas supply	Strengthen natural gas management	Promote the utilization and development of natural gas.
1978–2000	3	1	1	0
2001–2005	3	3	2	3
2006–2010	7	7	3	6
2011–2015	7	5	8	8
2016–2020	7	10	11	23
2021–2025	8	9	16	39
Total	35	35	40	79

2) The inverse disparity in upstream and downstream policy supply is widening.

From the perspective of dynamic evolutionary trends, the divergent gap between upstream and downstream policy supply has been continuously widening over time. Between 1978 and 2000, this disparity was not yet significant. However, since 2011, this pattern has reversed: during the period 2021–2025, downstream policy supply has nearly reached five times that of upstream policy supply. In contrast, "accelerated development" -related policies have virtually stagnated in terms of quantity.

This evolution is closely linked to the phased nature of the policy agenda. After the 12th Five-Year Plan (2013) incorporated unconventional natural gas into the national strategy, the "accelerate development" objective was initially focused on sectors such as shale gas and coalbed methane. However, with the comprehensive rollout of the "Coal-to-Gas" policy in 2017 and the formal introduction of the "Dual Carbon" goals in 2021, policy focus has rapidly shifted toward downstream utilization segments. Although the 2025 "Guiding Opinions on Promoting the High-Quality Development of Energy Equipment" explicitly calls for "focusing on large-scale development of deep-earth and deep-water oil and gas resources, accelerating production growth for unconventional oil and gas resources, and significantly improving recovery rates at existing oil fields," the actual distribution of policy instruments across sectors reveals that the policy support for the upstream sector has not kept pace with this demand.

3) The practical consequences of insufficient upstream policy support

The structural imbalance in upstream and downstream policy frameworks has given rise to tangible consequences across multiple sectors. In the shale gas sector, central government subsidy rates have shown a declining trend over the years: they stood at RMB 0.3 per cubic meter from 2016 to 2018, before being reduced to RMB 0.2 per cubic meter during 2019-2020. Although the "Administrative Measures for the Special Fund for Clean Energy Development" issued by the Ministry of Finance in 2025 established a five-year stable funding cycle covering 2025-2029 and adopted a "reward-based rather than direct subsidy" approach, the gap between the subsidy amount and the actual extraction costs of shale gas continues to widen. In the field of basic research, the national major science and technology project titled "Development of Large Oil and Gas Fields and Coalbed Methane" - which concluded in 2020 - lacks a clear follow-up mechanism; as a result, some basic research projects have been interrupted due to a lack of subsequent funding support. Regarding the cultivation of disruptive technologies, the current policy framework demonstrates a notably weak willingness to support high-risk, long-cycle upstream technologies. Taking coalbed methane exploration and development as an

example: China possesses abundant coalbed methane resources, yet there is insufficient exploration and surveying, inadequate integration and application of scientific research capabilities, and a disconnect between technological R&D and industrial demand. Such foundational frontier technologies, which possess disruptive potential, require long-term, stable policy support to bridge the gap from laboratory research to commercial field deployment; however, the current policy framework is more inclined to fund projects that can yield measurable outcomes within a short timeframe, thereby creating a structural barrier to original innovation.

3.2. Tool Dimension: An Institutional Imbalance Characterized by Flexible Dominance and Rigid Absence

1) Distribution structure of policy document types

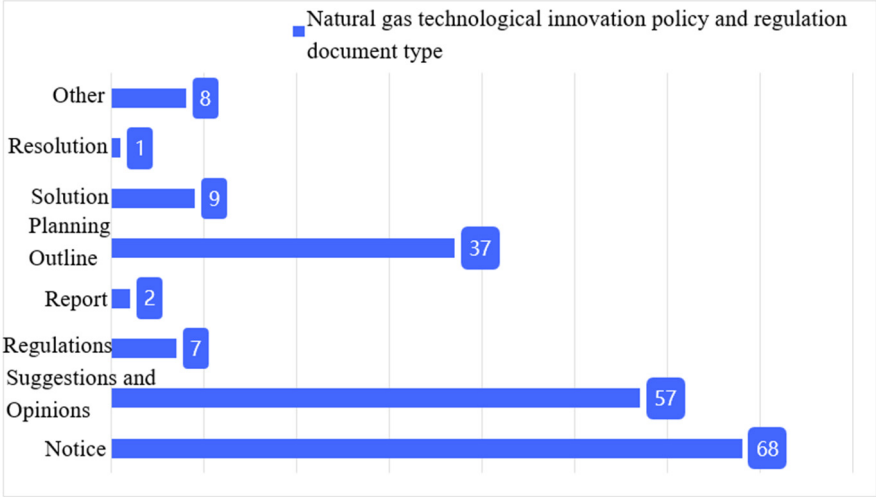


Figure 1. Types of official documents related to natural gas technological innovation policies and regulations

The selection of policy instruments directly determines the intensity and effectiveness of policy implementation. Figure 1 illustrates the distribution of document types across the sample of 189 policies; the combined share of three types of flexible policies-notices, recommendations and suggestions, and planning frameworks-amounts to 85.72%. In contrast, there are only nine policies with mandatory legal force. These data reveal a profound paradox: initiatives in natural gas technological innovation-such as the localization of equipment, data sharing, and safety standards-all entail substantial compliance costs for enterprises; yet the policy framework primarily relies on flexible language-such as "encouragement," "recommendation," and "support" -to drive these efforts. The "Several Opinions on Accelerating the Promotion of Digital and Intelligent Energy Development," issued by the National Energy Administration in 2023 and classified as an "Opinions" -type document, sets the goal of promoting the comprehensive application of digital and intelligent technologies across the entire oil and gas production, supply, storage, and distribution chain; however, it lacks supporting mandatory implementation clauses. In the absence of binding penalty mechanisms, the effectiveness of policy implementation depends heavily on the voluntary cooperation of enterprises.

2) Multidimensional manifestations of implementation challenges

The institutional framework dominated by flexible regulatory tools has encountered implementation challenges across multiple sectors. In the coalbed methane development sector, multi-departmental management lacks unified coordination and organizational structure; environmental monitoring primarily relies on self-reported data submitted by enterprises; and there are no quantitative regulatory standards or regular monitoring mechanisms for methane fugitive emissions. In the refining and chemical industry sector, the controls on volatile organic compound (VOC) emissions merely

establish general principles regarding total emission limits without specifying detailed standards tailored to enterprises of different sizes, resulting in inconsistent enforcement approaches. In the old oilfield pipeline sector, 2022 data from the Ministry of Emergency Management indicate that nearly 100,000 kilometers of pipelines nationwide exhibit varying degrees of aging; however, current regulations lack mandatory inspection schedules for pipelines in service for more than 20 years, and the adoption rate of technologies such as magnetic flux leakage internal inspection remains low.

3) The institutional framework for rigid tools is just beginning to take shape.

Notably, the simultaneous issuance of three regulatory documents-the *Administrative Measures for the Planning, Construction and Operation of Oil and Natural Gas Infrastructure*, the *Administrative Measures for Natural Gas Utilization*, and the *Administrative Measures for the Special Fund for Clean Energy Development* - released in 2025, indicates that policymakers have recognized the limitations of a framework dominated by flexible instruments and have begun to supplement this with a more robust institutional framework of rigid instruments.

3.3. Subjective Dimension: Formalization of Cross-departmental Collaboration Versus Functional Silos

1) Network characteristics identified in a jointly issued document by central government departments

Table 2. Key issuing authorities at the central level and number of documents issued

Issuing Authority	Quantity/Items		Issuing Authority	Quantity/Items	
the State Council	12	(1)	Ministry of Natural Resources	1	
Ministry of Industry and Information Technology	3	(5)	Ministry of Housing and Urban-Rural Development	3	(3)
National Energy Administration	9	(7)	State Administration for Market Regulation		(3)
National Development and Reform Commission	11	(18)	Ministry of Science and Technology	3	(9)
the Ministry of Finance	1	(4)	Environmental Protection Department		(1)
Ministry of Land and Resources	3	(5)	State Economic and Trade Commission	3	(2)
State Taxation Administration		(1)	Ministry of Agriculture and Rural Affairs		(3)
Ministry of Ecology and Environment		(3)	Ministry of Transport	5	(3)
National People's Congress Standing Committee	1		ministry of education		(3)
the People's Bank of China		(3)	department of commerce		(4)
State Post Office		(1)	National Railway Administration		(1)
Civil Aviation Administration of China		(1)	customs head office		(1)
National Forestry and Grassland Administration		(1)			

Note: The figure in parentheses represents the total number of jointly issued documents; for institutions that have changed their names or adjusted their functions during the statistical period, this document classifies them under the current institutional name at the time of document issuance.

Table 2 illustrates the policy-making activities of the primary issuing authorities at the central level. In terms of the total number of joint documents issued, there were 28 cross-departmental joint documents (the actual number of documents after deduplication), indicating that a certain foundation for interdepartmental collaboration already exists. However, a deeper analysis of the network

structure of these joint documents reveals that the "formalized" nature of such collaboration remains prominent.

First, coordination is highly concentrated in a small number of core departments. Among the 28 jointly issued documents, 18 were issued with the participation of the National Development and Reform Commission (NDRC), accounting for 64.29% of all jointly issued documents; this implies that should the NDRC's coordination efforts on a particular issue weaken, there could be a gap in cross-departmental policy supply. Second, key supporting departments within the innovation ecosystem exhibit functional deficiencies: the Ministry of Education participated in only 3 jointly issued documents, the Ministry of Commerce in 4, and the People's Bank of China in 3.

2) The institutional root cause of redundant innovation platform development

Another typical consequence of inadequate interdepartmental coordination is the redundant establishment of innovation platforms. There is a lack of coordinated planning among three types of platforms-key laboratories approved by the Ministry of Science and Technology, engineering research centers authorized by the National Energy Administration, and provincial-level platforms established in a race by local governments at all levels. The institutional root of this situation lies in the fact that the respective competent authorities use the number of newly established platforms as a performance evaluation metric, prompting them to compete in applying for funding, yet they lack an overall accountability mechanism for the efficiency of the entire innovation chain. From 2025 to 2026, the Chinese government promoted the restructuring and consolidation of the National Key Laboratories for Oil and Gas; while the merger of some national-level platforms has been completed, the coordinated integration of provincial and enterprise-level platforms still lags behind.

4. INSTITUTIONAL ATTRIBUTION: A FRAGMENTED GENERATIVE LOGIC

4.1. The Fragmented Administrative System and the Departmental Self-interest Tendency

China's science and technology management system has long been characterized by a fragmented, "vertical" structure: the National Development and Reform Commission is responsible for project approval and investment management; the Ministry of Science and Technology oversees the allocation of R&D funding; the National Energy Administration coordinates industry-wide planning; and the Ministry of Ecology and Environment is responsible for emission standards and environmental protection inspections. The performance evaluation objectives across these departments vary significantly, and no cross-departmental joint accountability mechanism has been established to measure the "full-chain innovation efficiency of the natural gas sector." As a result, there is a tendency among these departments to operate in isolation within their respective jurisdictions, without any overarching coordination for the overall strategic layout. The highly overlapping research directions and redundant equipment procurement observed across the various national shale gas development platforms described above are a vivid illustration of the self-interested behavior exhibited by these departments under this fragmented, sectoral and hierarchical management framework.

4.2. Policy Volatility Driven by Short-term Political Agendas

An analysis of the trend in the number of policies reveals that policy peaks closely align with major political agendas. In 2013, the State Council introduced a special policy on coalbed methane development, which drove a 129% year-on-year increase in the number of relevant policies that year; in 2017, the peak period for the "coal-to-gas" initiative spurred a 700% year-on-year surge in local-level policies; and following the announcement of the "Dual Carbon" goals in 2021, the number of

policies continued to rise sharply. While this policy diffusion pattern enables rapid response to national strategic priorities, it also leads to a concentration of policy resources on short-term issues, lacking long-term, rolling planning oriented toward the 2035 and 2050 horizons.

4.3. The "Avoiding Major Issues and Focusing on Minor Ones" Incentive Approach and the Misalignment of Performance Evaluation Systems

The current science and technology management system shows a significantly stronger preference for "explicit political achievements" than for investing in "implicit foundational research." Quantitative indicators-such as the number of platforms or the number of patents-are assigned excessive weight, whereas "slow-moving variables" -such as breakthroughs in fundamental research that require long-term accumulation or the development of pilot-scale validation capabilities-are selectively overlooked because it is difficult to generate demonstrable outcomes within a short timeframe. This incentive structure directly leads government agencies to favor approving "short-term, quick-return" technology integration projects over long-term fundamental research; enterprises tend to adopt mature foreign technologies rather than engage in high-risk original innovation; and universities prefer publishing academic papers over advancing the pilot-scale commercialization of research findings. Although breakthroughs in core technologies-such as shale gas fracturing-have been identified as priority areas in numerous policy documents, the development of fracturing fluid formulations, downhole tools, and field construction techniques are supported by separate, disjointed specialized programs; the lack of coordination among these individual policies creates gaps in the industrial chain.

5. RESEARCH FINDINGS AND POLICY RECOMMENDATIONS

5.1. Research Conclusion

This study, based on 189 natural gas technological innovation policy texts, constructs a three-dimensional analytical framework of "Objective -Tool -Actor" to systematically reveal the inherent fragmentation characteristics of the policy system. The research indicates that China's natural gas technological innovation policies are trapped in a dilemma characterized by "quantitative abundance but structural imbalance." From the objective dimension, the downstream "promote utilization" policies and the upstream "accelerate development" policies create a significant "scissors gap," leading to severe misallocation of innovation resources across the industrial chain; from the tool dimension, flexible policies-such as notices and opinions-account for as high as 85.72% of all policies, whereas rigid constraints-such as regulations and measures-account for less than 9%, placing the policy system within the "soft constraint" trap; from the actor dimension, cross-departmental joint policy issuances are concentrated among a few core departments, such as the National Development and Reform Commission, while key supporting departments-such as the Ministry of Education, the Ministry of Commerce, and the People's Bank of China-lack adequate functional presence, resulting in a pattern of "formal coordination but substantive isolation." The institutional roots of this triple fragmentation lie in the fragmented administrative system, policy volatility driven by short-term political agendas, and an assessment and incentive mechanism that tends to "avoid addressing critical issues."

5.2. Policy Proposal

1) Optimize the cross-link allocation of policy attention

The root cause of the problem does not lie in specific policy provisions, but rather in the absence of an institutionalized mechanism to channel policy focus toward upstream sectors. Therefore, it is essential to establish a goal-oriented guidance mechanism for natural gas technological innovation,

clearly define strategic priorities for upstream sectors within the national long-term energy planning framework, and foster a more balanced resource allocation pattern across all segments of the industrial chain. For upstream sectors-such as deep-earth exploration, deep-sea operations, and unconventional resources-where breakthroughs are particularly challenging, a long-term funding mechanism with a cycle of 5–10 years should be established to provide sustained support for basic research that may not yield immediate results but holds strategic value. Additionally, a target-listing system should be implemented to address key upstream technological challenges, with a focus on areas such as the efficient development of shale gas, deep-sea oil and gas engineering equipment, and deep-earth drilling and production equipment, thereby guiding the orderly concentration of innovation resources.

2) Hierarchical framework for strengthening the binding force of policy instruments

Systematically identify key institutional gaps in the field of natural gas technological innovation, and facilitate the orderly transition of policy matters involving significant externalities-such as public safety, environmental protection, and data sharing-from "notices" and "opinions" to "measures" and "regulations." Taking the simultaneous issuance of three departmental regulations by 2025 as an opportunity, gradually establish an instrumentarium that appropriately combines flexible guidance with rigid constraints during the 15th Five-Year Plan period. At the same time, care should be taken to avoid the excessive use of rigid instruments, and the type of instrument should be selected differently depending on the nature of the policy matter and the intensity of its externalities.

3) Enhance the institutionalized channels for cross-departmental collaboration.

Translate cross-departmental coordination from a temporary arrangement into an institutionalized, routine mechanism; in response to the multi-stakeholder collaboration requirements involved in tackling key upstream core technologies, establish a cross-departmental coordination system led by the State Council or the National Energy Administration, incorporating the Ministry of Science and Technology, the Ministry of Education, the Ministry of Commerce, the People's Bank of China, and other relevant agencies into a permanent deliberative framework. Incorporate the "full-chain innovation efficiency in the natural gas sector" into the joint performance evaluation targets of all relevant departments, thereby shifting the evaluation approach from a "sectoral responsibility" model to a "full-process shared responsibility" model. Regarding the development of innovation platforms, establish a regular assessment and dynamic adjustment mechanism for national-level innovation platforms; promote the consolidation of platforms with highly overlapping research directions, and establish an exit mechanism for platforms that have failed to deliver substantive innovative outcomes over the long term, thereby fundamentally correcting the tendency to prioritize platform listing over actual R&D investment.

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