STUDY OF INNOVATION AND TECHNOLOGY IN CHINA

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Critical Factors in Enabling Defense Innovation: A Systems Perspective

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This brief provides an analytical framework to identify, categorize, and assess the diverse array of factors that are involved in the pursuit of defense innovation, as viewed through an innovation ecosystem prism. Defense innovation systems are engaged in highly complex, time-consuming and resource-intensive work. Innovation does not occur in isolation but requires extensive interaction and inputs from many sources and should be viewed from a broad-based and systemic perspective. Many of the insights from this framework are derived from an extensive examination into the state of innovation in the contemporary Chinese defense science, technology, and industrial system, examined in more detail in the next brief in this volume.

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DEFINING THE DEFENSE INNOVATION SYSTEM AND ITS KEY ELEMENTS

Defense innovation is defined in this brief as the transformation of ideas and knowledge into new or improved products, processes, and services for military and dual-use applications and refers primarily to organizations and activities associated with the defense and dual-use civil-military science, technology, and industrial base. Included at this level are, for instance, changes in planning, programming, budgeting, research, development, acquisition and other business processes.[1]

A defense innovation system is a network of organizations that interactively pursue defense-related science, technology, and innovation activities to further the development of a country's defense, dual-use civil-military, and strategic high-technology interests and capabilities. While many countries seek to keep as much of their defense innovation systems within national boundaries, this has become increasingly difficult with globalization and the enormous investment and resources required to engage in technology development and has led to growing levels of multinational collaboration.

Two aspects of this definition of the defense innovation system are worth highlighting. First, *organizations* are entities directly or indirectly involved in supporting the innovation process. They include research institutes, universities, state and party agencies, military units, defense industrial agencies, and state-owned and private enterprises at the central and local levels. Second, *activity* and interaction between organizations is carried out through well-defined institutional arrangements, which consist of norms, routines, habits, established practices, and other rules of the game that guide the workings of the system.

IDENTIFYING AND CATEGORIZING CRITICAL FACTORS IN THE DEFENSE INNOVATION SYSTEM

Defense innovation systems come in all shapes and sizes, but those that are highly capable in the development and building of major weapons capabilities need to maintain huge, sprawling, and extremely complex apparatuses. In examining the factors that may account for the success or failure of these innovation systems, there is an overflowing smorgasbord of drivers, dynamics, and variables to choose from. We offer two approaches to impose analytical order to this universe of factors. The first is to sort these factors into 'hard' and 'soft' innovation variants, and the second is to categorize them into several distinctive domains based on their functions.

Hard and Soft Innovation Factors

The defense innovation ecosystem has innovation attributes and capabilities that can be divided into 'hard' and 'soft' categories.[2] Hard innovation capabilities are input and infrastructure factors intended to advance technological and product development. These include research and development (R&D) facilities such as laboratories, research institutes, and universities, human capital, firm-level capabilities and participation, manufacturing capabilities, access to foreign technology and knowledge markets, availability of funding sources from state and non-state sources, and geographical proximity, such as through clusters. These hard innovation capabilities attract the most analytic attention because they are tangible and can be measured and quantified.

Soft innovation capabilities are broader in scope than hard factors and cover political, institutional, relational, social, ideational, and other factors that shape non-technological and process-related innovative activity. This is what innovation scholars define as "social capability."[3] These soft capabilities include organizational, marketing, and entrepreneurial skills as well as governance factors such as the existence and effectiveness of legal and regulatory regimes, the role of political leadership, promotion of standards, corporate governance mechanisms, and the general operating environment within which the ecosystem is located.

In the case of China, a diverse array of hard and soft innovation factors have played important roles in the far-reaching transformation of its defense innovation system. Hard factors include:

1. resource allocations
2. research and development capabilities
3. manufacturing capabilities
4. access to foreign technology transfers
5. shifting the main impetus for technology development from defense industry dominance or technology push to a more war-fighter-driven process, or demand pull
6. effectiveness of the acquisition system

1 Tai Ming Cheung, Thomas G. Mahnken, and Andrew L. Ross, "Frameworks for Analyzing Chinese Defense and Military Innovation," in *Forging China's Military Might: A New Framework for Assessing Innovation*, ed. Tai Ming Cheung (Baltimore, MD: Johns Hopkins University Press, 2014).

2 For an expanded discussion, see Tai Ming Cheung, "The Chinese Defense Economy's Long March from Imitation to Innovation," *Journal of Strategic Studies* 34, no. 3 (2011).

3 Moses Abramovitz, "Catching Up, Forging Ahead, and Falling Behind," *Journal of Economic History* 46, no. 386 (1986).

7. doctrine and strategy
8. corporate drivers

Prominent soft factors include:

1. high-level leadership support
2. forging of a new state regulatory oversight model
3. cultivating new institutional culture and governance norms
4. constructing a modern regulatory and standards-based regime
5. improving technology diffusion
6. the external threat environment

Functional Categories

While the above definition of the defense innovation system provides a general overview of its organization and operational features, a more nuanced understanding of how the system functions requires a detailed examination of its numerous constituent parts and processes. In the examination of the Chinese defense innovation system, for example, at least 22 factors were identified as playing important parts in the innovation process. These variables can be sorted into five general categories according to their role and impact on the defense innovation process: catalytic, input, process, institutional, and output (Figure 1).

Catalytic factors are the sparks that ignite innovation of a more disruptive nature. These powerful factors are normally external to the defense innovation system. Their intervention occurs at the highest and most influential levels of the ecosystem and can produce the conditions for enabling considerable change and disruption. Without these catalytic factors, the defense innovation system would find it very difficult, if not impossible, to engage in higher-end innovation and remain tied to routine modes of incremental innovation.

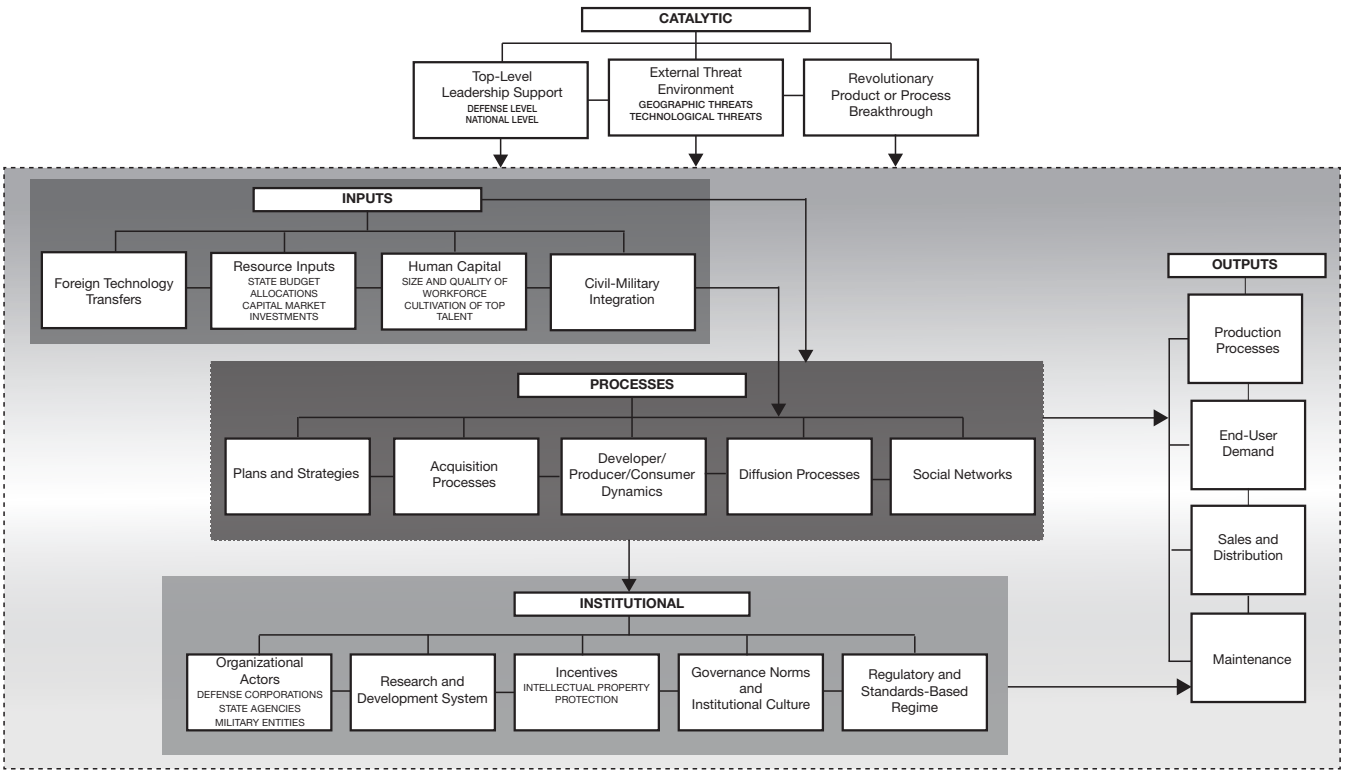
Input factors refer to material, financial, technological, and other forms of contributions that flow into the system. Most of these inputs are externally sourced but can also come internally. Resource allocations, technology transfers, and military civil fusion are important input factors.

Process factors are the procedures, routines, and interactions that enable the innovation system to operate smoothly. Important processes in the case of the Chinese defense innovation system, for example, include the workings of the acquisition system, technology push versus demand pull dynamics, and the design and implementation of plans and programs.

Institutional factors are the structural and normative mechanisms, actors, and rules that anchor the innovation system and play a major role in governing how it works. They include the governance regime, standards, legal and administrative regulations, the role of corporations, and state and military agencies.

Output factors are responsible for determining the nature of the products and processes that come out of the innovation system. They include

FIGURE 1. Key categories of factors in the defense innovation system



the production process, maintenance, the role of market forces such as marketing and sales considerations, and the influence of end-user demand.

It should be pointed out that the 'hard-soft' and functional factors frameworks are not dueling approaches but can be integrated to offer an even more nuanced categorization of the factors at play in the defense innovation system (Table 1).

FROM CATEGORIZATION TO DISTINGUISHING INNOVATION OUTCOMES

This categorization of the universe of factors that help to shape and impact how innovation occurs within the defense innovation system is the first step of analysis. The next step is to determine the role and influence of key factors and their interconnections with other factors to produce a particular innovation outcome. Innovation comes in different forms that range from simple copying at one end to highly sophisticated disruptive innovation at the other (Figure 2).

Duplicative imitation: Products, usually obtained from foreign sources, are closely copied with little or no technological improvement. This is the starting point of industrial and technological development for latecomers. The process begins with the acquisition of foreign technology, which then goes directly into production with virtually no technology or engineering and manufacturing development.

Creative imitation: This represents a more sophisticated form of imitation that generates imitative products with new performance features. Domestic research input is relatively low, but is beginning to find its way into modest improvements in components or non-core areas. The development process becomes more robust with more work done in the technology development and engineering and manufacturing stages. The work here is primarily how to integrate domestic components into the dominant foreign platform.

Creative adaptation: Products are inspired by existing foreign-derived technologies but can differ from them significantly. One of the primary forms of creative adaptation is reverse engineering. There is considerably more research conducted here than in the creative imitation stage, especially in product or concept refinement, and there is also significantly more effort and work to combine higher levels of domestic content onto an existing foreign platform. This can also be called advanced imitation.

Crossover innovation: This refers to products jointly developed with foreign partners, with significant technology and knowledge transfers to the local side that result in the creation of a R&D base able to conduct independent and original innovation activities. However, there is still considerable reliance on foreign coun-

TABLE 1. Key factors driving the Chinese defense innovation system incorporating the hard-soft and function factors categories

Factor types	Hard innovation factors	Soft innovation factors
Catalytic	Revolutionary product or process breakthrough opportunities	Top-level leadership support External threat environment
Input	Foreign technology transfers Resource inputs (state budget allocations, capital market investments) Human capital (size and quality of workforce, cultivation of top talent)	
Process	Plans and strategies Manufacturing process Acquisition (research, development, and engineering) system	Technology push versus demand pull Technological diffusion
Institutional	Organizational actors (defense corporations, state agencies, military entities) Research and development system	Regulatory and standards-based regime Incentives (intellectual property protection) Governance norms Relationship between the state and defense firms
Output	Production process Maintenance Sales and distribution	End-user demand

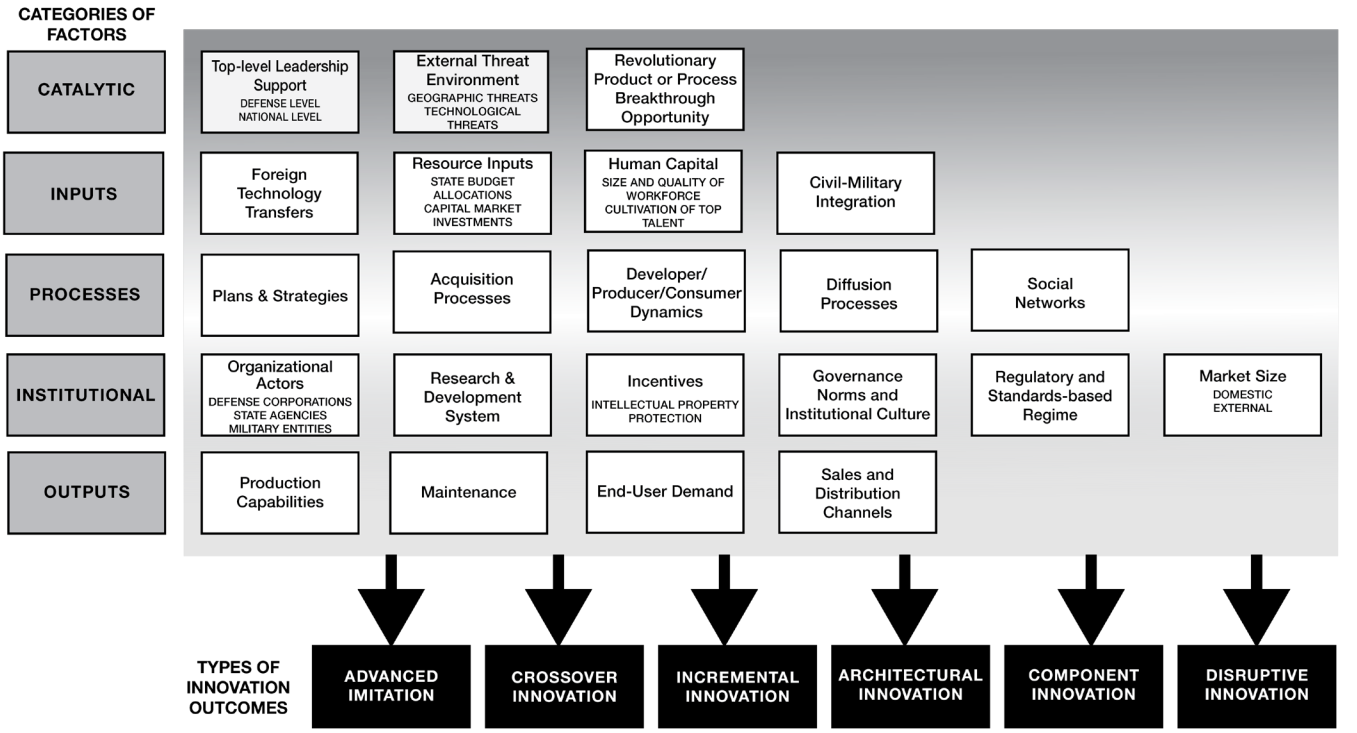


FIGURE 2. Factor categories and innovation outcome types

tries for technological and managerial input to ensure that projects come to fruition.

Incremental innovation: This is the limited updating and improvement of existing indigenously developed systems and processes. Incremental innovation can be the gradual upgrading of a system through the introduction of improved subsystems, but it is also often the result of organizational and management inputs aimed at producing different versions of products tailored to different markets and users, rather than significant technological improvements through original research and development.

Architectural innovation: There are two variants to architectural innovation: product and process. Architectural product innovation refers to "innovations that change the way in which the components of a product are linked together, while leaving the core design concepts (and thus the basic knowledge underlying the components) untouched."[4] Architectural process innovation refers to the redesign of production systems in an integrated approach (involving management, engineers, and workers as well as input from end-users) that significantly improves processes but does not usually result in radical product innovation. The primary enablers are improvements in organizational, marketing, management, systems integration, and doctrinal processes and knowledge that are coupled with a deep understanding of market requirements and close-knit relationships between producers, suppliers, and users. As these are the same factors responsible for driving incremental innovation, distinguishing between these different types of innovation poses a major analytical challenge. While many of the soft capabilities enabling architectural innovation may appear to be modest and unremarkable, they have the potential to cause significant, even discontinuous consequences through the reconfiguration of existing technologies in far more efficient and competitive ways that challenge or overturn the dominance of established leaders.

Component or modular innovation: This involves the development of new component technology that can be installed into existing system architecture. Modular innovation emphasizes hard innovation capabilities such as advanced R&D facilities, a cadre of experienced scientists and engineers, and large-scale investments.

Radical or disruptive innovation: This requires major breakthroughs in both new component technology and architecture. Only countries with broad-based, world-class R&D capabilities and personnel along with deep financial resources and a will-

4 Rebecca Henderson and Kim Clark, "Architectural Innovation: The Reconfiguration of Existing Product Technologies and the Failure of Established Firms," *Administrative Science Quarterly* 35, no. 1 (1990): 10.

ingness to take risk can engage in this activity.

For the contemporary Chinese defense innovation system, the primary types of innovation outcomes are advanced imitation and incremental innovation, although there are growing signs of higher levels of innovation outcomes such as crossover and architectural innovation. This is because the most important factors are activities that focus on absorption, such as foreign technology imports, or are soft innovation factors, like end-user demand and plans and strategies. Important factors that would indicate that the most advanced types of innovation outcomes are gaining traction are still weak, such as the role of the acquisition process, the R&D system, incentive mechanisms, governance norms and institutional culture, and production processes. Overall, this indicates that the locus of China's defense innovation capabilities is between an advanced imitation to a low-to-mid tier innovation power.

PATHWAYS TO INNOVATION SUCCESS

The pathways to these different types of innovation outcomes depend on a number of key considerations. The first is the level of sophistication and development of the overall defense innovation system. Advanced, mature, and well-endowed systems such as those of the United States and Western European states are far more able to pursue higher-end innovation than underdeveloped, immature, catch-up apparatuses that will be primarily limited to imitation and lower-end innovation.

A second consideration are the linkages between factors, especially between the different categories. Close working connections between catalytic factors and input, process, and institutional-related factors would enable higher levels of innovation outcomes. For example, a strong blueprint for success would be if top leadership support is closely tied to resource inputs such as budgets, acquisition processes, plans and strategies, and organizational actors such as policy implementation bodies. But if leadership support is not tightly affiliated with critical enabling factors elsewhere in the innovation system, then the pathways to progress will be absent.

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