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# A Review of a New Technological Catch-Up Framework for Latecomers: Some Strategic Lessons for Iran

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## Abstract

Nowadays, technological and innovative capabilities are widely recognized as the fundamental pillars of international competitiveness and sustainable economic development. Their significance is particularly pronounced in the industrial sector, where they drive productivity growth, create new market opportunities, and enhance value-added production. Given these advantages, narrowing the technological gap between pioneering economies and latecomer countries, commonly referred to as technology "catch-up", has become a central concern in the literature on innovation capability development. This article aims to develop a comprehensive framework for technology catch-up tailored to the conditions faced by latecomer countries. The proposed framework is structured around four interconnected axes: the institutional environment, the technology regime, firm-level capabilities, and catch-up strategies. These four dimensions collectively outline the scope and direction of government policies and strategic interventions aimed at facilitating technology catch-up within the national innovation system. What distinguishes this framework from previous models is its integrative perspective. While earlier studies have tended to focus either narrowly on firm-level processes or broadly on national systems of innovation, this framework bridges these levels by explicitly linking macro-institutional conditions with technological regimes and firm-level strategies. As a result, it offers a coherent, actionable, and policy-oriented analytical tool that can assist developing countries in designing more effective innovation policies and fostering sustainable industrial upgrading in an increasingly competitive global economy.

**Keywords:** Supply Chain Resilience; Institutional Constraints; Energy Disruption; Post-Conflict Economic Recovery

## چکیده

توانمندی‌های فناورانه و نوآورانه، ارکان بنیادین رقابت‌پذیری بین‌المللی و توسعه پایدار اقتصادی به‌شمار می‌روند؛ اهمیتی که در بخش صنعت به‌واسطه ارتقای بهره‌وری، خلق بازارهای نوین و تولید با ارزش‌افزوده بالا نقشی تعیین‌کننده دارد. از این‌رو، تقلیل شکاف فناورانه میان اقتصادهای پیشرو و کشورهای پس‌افتاده (نوظهور)، موسوم به «جهش و پویایی فناورانه»، به یکی از مباحث محوری در ادبیات توسعه نوآوری بدل شده است. این مقاله در پی تدوین چارچوبی جامع برای جهش فناورانه متناسب با مختصات کشورهای پس‌افتاده است. الگوی پیشنهادی بر چهار محور به‌هم‌پیوسته محیط نهادی، رژیم فناورانه، قابلیت‌های سطح بنگاه و استراتژی‌های پی‌جویی و جهش استوار است و این ابعاد چهارگانه به‌طور هم‌افزا جهت‌گیری و دامنه مداخلات سیاستی و راهبردی دولت را درون نظام ملی نوآوری تبیین می‌کنند. وجه تمایز این چارچوب نسبت به مدل‌های پیشین، اتخاذ رویکردی تلفیقی و چندسطحی است. برخلاف مطالعات گذشته که یا بر سازوکارهای خرد درون‌بنگاهی متمرکز بوده و یا صرفا به سطح کلان نظام‌های نوآوری پرداخته‌اند، این الگو با پیوند زدن الزامات نهادی، ویژگی‌های رژیم فناوری و راهبردهای بنگاهی، پلی میان سطوح خرد و کلان برقرار می‌سازد. در نتیجه، این پژوهش ابزاری سیاستی، منسجم و عملیاتی برای هدایت کشورها به سوی ارتقای صنعتی و تاب‌آوری در اقتصاد رقابتی بین‌المللی ارائه می‌دهد.

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# 1. INTRODUCTION

## 1-1. The Role of Government in the Development of Technology and Innovation

Progressive governments have always supported knowledge production and the development of technology and innovation as one of the pillars of government policy. The importance of formulating innovation policies is underscored by the emergence of failures that arise in this process. Therefore, innovation policy is defined as "a set of tools and measures to correct some failures in the process of developing technological and innovative capabilities" (IMF, 2019). The failures faced by the innovation system can be classified as follows.

### I. Market Failure:

Market failure is the basic premise for applying innovation policies. In market failure, actors are assumed to adjust their behavior according to their private interests. Because knowledge has public-good characteristics and its social benefits may exceed the private benefits to individual firms, it is necessary for the government to make targeted interventions to encourage investment in knowledge and technology with a long-term perspective. In today's knowledge-based economy, unintended knowledge spillovers can exacerbate market failures. For example, governments use various methods to protect innovators' economic returns through policies such as patent protection and intellectual property rights.

Because innovation-related market failure partly arises from the public-good characteristics of knowledge and the spillovers that innovators cannot fully appropriate, the government is recommended to subsidize research and development (R&D) and to support the interests of innovative firms and sectors through intellectual property rights. In developing countries, capabilities are often limited, and there is little ability to conduct R&D within firms. Therefore, simply using tools to stimulate the supply of innovation will not be productive unless firm-level capabilities to create innovation are thoroughly addressed.

### II. Capability Failure

Capability failure refers to a situation where the company lacks the necessary knowledge and skills to develop technology and innovation, including limited technological capabilities, weak learning capabilities, lack of absorptive capacity, and lack of managerial capabilities.

### III. System Failure

In the Schumpeterian tradition, system failure is also important. System failure at the system level refers to dysfunction in the national innovation system of a country, which includes companies, universities, public research laboratories, government agencies, and financial institutions. Various reasons can be listed for system failure, such as limited capabilities among actors, lack of effective rules to create motivation and opportunities for cooperation, and related factors. Weak abilities at the industry or university level (capability failure) lead to lack of cooperation, coordination, and effectiveness of the innovation system (system failure). Despite many differences between developed and developing countries, most innovation systems in developing countries try to emulate those of developed countries (Viotti, 2002). This leads to system inefficiency ultimately resulting in system failure, as tools and policies cannot perform effectively.

### IV. Size Failure

Along with the development of technology and economic transition toward the frontiers of technology (high-tech industries), the processes related to R&D and technology development become more complex and expensive. This requires large companies to have the capacity to manage the technology catch-up process. Size failure occurs when firms may fail to achieve sufficient scale because of these factors.

The following table compares the four types of failure. While in advanced countries, market failure and system failure are among the major challenges of the innovation system, in developing countries, all four types of failure can hinder the development of technology and innovation systems.

Table 1 – Comparison of types of failures in the innovation system

| | Capability failure, | market failure | system failure | size failure |
|---|---|---|---|---|
| Focus | Firms | Market institution | innovation system (actors and their interactions) | business environment and firms |
| Factor | Lack of firm-level capabilities | Lack of supply side driving incentives in innovation | Lack of actors' capabilities, institutional structure and inefficient governance | Lack of tools to adjust the corporate structure |
| Solution | Consulting and training services Facilitating the acquisition and accumulation of knowledge | Incentives Compliance with intellectual property rights | adjusting the structure of the innovation system | supporting the creation of business groups, consortium Facilitate the merger and acquisition process Revision of licensing conditions |
| Type of countries | Developing | Developing and developed | Developing and developed | Developing |

## 1-2- Innovation Policy Challenges in Developing Countries

Due to the relatively lower quality of institutional and governance mechanisms in developing countries, the effectiveness and efficiency of innovation policies in these countries are often limited. This makes it impossible to prescribe a single combination of innovation policies for all countries; each country needs a specific combination of innovation tools according to its requirements (degree of growth and maturity of the innovation system). Some of the challenges faced by developing countries in developing their innovation systems include the following:

### I. Inability to manage and implement complex innovation policies because of limited government capabilities

The most important challenge for developing countries in implementing innovation policy include market failure and system failure (World Bank Group, 2020). Low quality of research, a costly business environment, lack of testing and measurement infrastructure, and weaknesses in the financing system are among the most fundamental challenges.

### II. Inability to design effective policy packages

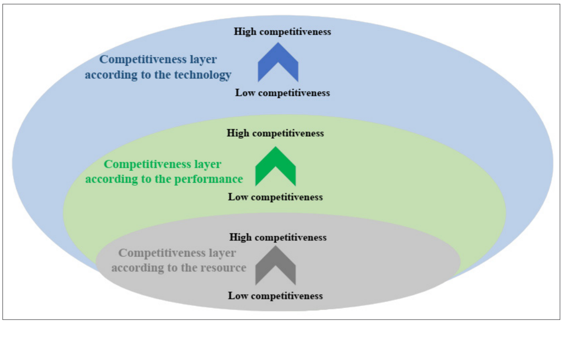
Another challenge is the business environment and the specific characteristics and level of development of each sector of the economy. The combination of technological capabilities within firms differs across countries; therefore, a one-size-fits-all policy cannot be applied universally. To resolve this challenge, policies need to be designed according to the business environment, technology level, and firm capabilities of each sector.

### III. Information gap on how to support innovation

This challenge refers to the information gap and lack of effective data to design appropriate policies supporting innovation. Most policymakers are not aware of the appropriate tools given institutional capacity and market conditions. In developing countries, the first priority should be to improve the availability and quality of information and data in order to adapt technology policies to the business environment.

### IV. Lack of attention to the layers of competitiveness development

In policymaking, attention should be given, apart from technology-related issues, is strengthening the competitiveness of industries and creating a development path from competitiveness based on resources to competitiveness based on efficiency and finally to competitiveness based on technology. Resource-dependent industries that are that have not yet achieved production efficiency do not have the necessary absorptive capacity to improve technology. This is an important point neglected in many policy programs in developing countries. As shown in Figure 1, in developing firms' competitiveness, competitiveness based on resources (relative advantages) should be linked to competitiveness based on technology by building competitiveness based on efficiency.




Source: Authors' compilation based on the literature reviewed.

**Figure 1- Layers of competitiveness development**

## 2- METHODOLOGY

### 2-1- Literature Search Strategy

This study adopts a structured narrative literature review combined with framework synthesis. The objective is not to estimate an aggregate effect size, but to identify the principal institutional, technological, firm-level, and strategic dimensions associated with technological catch-up in latecomer economies and firms. The review covers the core catch-up literature from the early 1990s through 2025, with particular attention to studies published after 2020 that address digital transformation, green technological change, global value-chain restructuring, and innovation policy.

The literature search focused on studies addressing technological catch-up, latecomer firms, technological capabilities, national and sectoral innovation systems, technology regimes, catch-up strategies, leapfrogging, digital transformation, green technology, global value chains, and innovation policy. The principal search terms were: “technological catch-up,” “technology catch-up,” “technological catching-up,” “latecomer firms,” “latecomer countries,” “technological capabilities,” “technology regime,” “national innovation system,” “catch-up strategy,” “leapfrogging,” “digital transformation,” “green technology,” “global value chains,” and “innovation policy.” The search was complemented by backward reference searching from seminal and highly relevant studies.

Inclusion criteria were: (1) studies addressing technological catch-up, technological learning, leapfrogging, or innovation upgrading; (2) studies examining latecomer firms, industries, or developing and emerging economies; (3) conceptual, empirical, or policy-oriented studies that identify determinants, mechanisms, strategies, stages, or windows of opportunity for catch-up; and (4) studies containing sufficient conceptual or empirical information to map their findings onto the proposed framework. Studies focused exclusively on innovation in advanced economies without a catch-up dimension, studies unrelated to technological or industrial upgrading, and publications without sufficient information to identify catch-up mechanisms were excluded.

The final literature base was purposively selected for conceptual relevance rather than statistical representativeness. This approach is appropriate because the purpose of the paper is to synthesize explanatory dimensions of catch-up and develop an integrative, policy-oriented framework rather than conduct a statistical meta-analysis.

Because the original manuscript did not preserve a detailed search log, the review does not report database-specific retrieval counts. The search strategy is therefore described transparently in terms of its scope, keywords, inclusion and exclusion criteria, and backward reference searching.

### 2-2- Framework Synthesis and Identification of the Four Pillars

The four pillars were derived through comparative framework synthesis. First, the major catch-up models reviewed in the paper were examined according to the level at which they explain catch-up and the principal factors they emphasize. Hobday (1995) primarily explains catch-up through firm-level technological learning and a progression from production to design and R&D. Lee and Lim (2001), Lee (2005, 2019), and Lee et al. (2017) emphasize technological regimes, government intervention, competitive conditions, and strategic choices. Miao et al. (2018), based on a review of more than 76 studies, distinguish external factors, particularly the institutional environment and technology regime, from internal factors such as technological capabilities and catch-up strategy.

Second, recurring concepts were grouped according to their analytical function. Government, institutions, infrastructure, policy, and the wider innovation and business environment were grouped under the institutional environment. Technological trajectories, technology life cycles, modularity, knowledge characteristics, appropriability, spillovers, and technological opportunities were grouped under the technology regime. Learning, absorptive capacity, production, organizational, managerial, and technological capabilities were grouped under firm capabilities. Path following, path skipping, path creating, OEM–ODM–OBM progression, and windows of opportunity were grouped under catch-up strategy.

Third, the four dimensions were cross-checked against the reviewed models and the more recent literature to assess conceptual coverage and internal consistency. This triangulation provided conceptual validation of the framework: each pillar is supported by multiple strands of the catch-up literature, while the framework connects macro-institutional, sectoral-technological, and micro-firm dimensions that are often treated separately. This is not empirical validation. The framework remains a conceptual model and requires future testing through comparative cases, expert assessment, and quantitative indicators.

The synthesis therefore produced four interconnected pillars: (1) institutional environment, (2) technology regime, (3) firm capabilities, and (4) catch-up strategy. The central proposition is that successful catch-up depends not on any single pillar but on their alignment: institutions create the operating conditions, the technology regime determines feasible opportunities, firms accumulate and deploy capabilities, and strategy converts those conditions and capabilities into upgrading trajectories.

## 2- Literature Review

Among the numerous models proposed for catch-up, Hobday's model focuses on the development of firm capabilities in the path of technology catch-up. Hobday (1995) argues that while the standard model of innovation in leading firms begins with R&D activities, this model does not suit lagging firms. Hobday's model for lagging firms, known as the reverse technology life cycle, begins with production, then moves to design, and finally to R&D. Hobday believes that focusing on R&D activities is not a proper catch-up strategy for latecomers. He maintains that, unlike traditional innovation models that place R&D at the center, lagging firms should first engage in simple activities such as product assembly and reverse engineering (Figure 2). According to Hobday, innovation for new entrants entails engineering efforts to improve production processes and reduce production costs (at least in the early stages), along with learning to make gradual changes. Continuous innovation is necessary for newcomers to reduce the technology gap with leading firms.

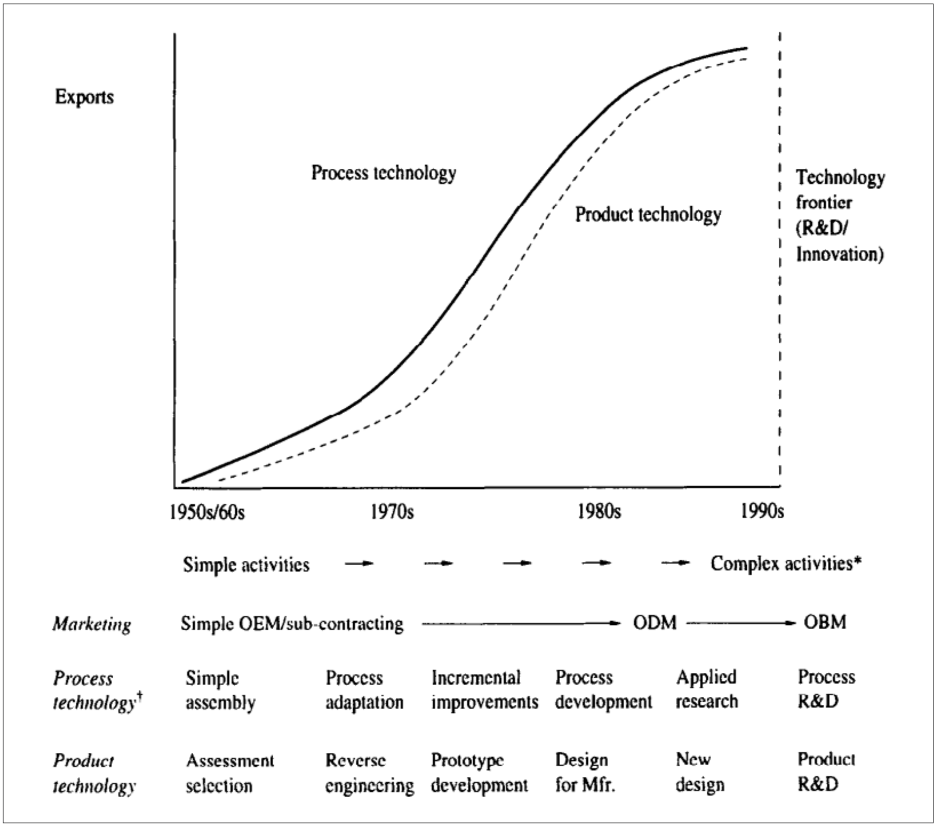



**Figure 2 - Hobday's path of technology catch-up (Hobday, 1995)**

Lee et al. (2017) introduced an alternative model of technology catch-up and highlighted three key components, "government role," "technology regime," and "competitive advantages", as key factors affecting technology catch-up (Figure 3). Of course, besides these components, one should also take into account product development, market positions, and firm strategies as three complementary factors. Lee et al. consider gaining market share as an index for successful technology catch-up. Therefore, along with government role, technology regime and competitive advantages (inspired by Porter's diamond model) are two important factors in the path of technology catch-up.

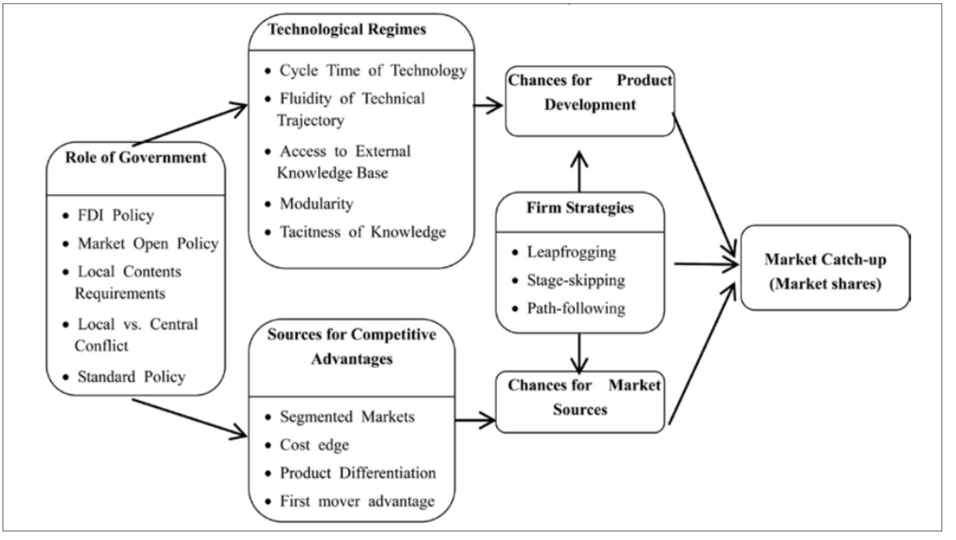



**Figure 3 – Lee et al. model of catch-up (Lee et al., 2017)**

In Lee et al.'s (2017) model, the government's role involves FDI policy, open market policies, infrastructure investment, and quality policy. Competitive advantage includes segmented markets, cost advantages, product diversification, and first-mover advantage. In this model, the technology regime is made up of five axes:

- Technology cycle time: Defined as the frequency of innovation in creating new technologies. For example, one new generation of technology may be developed each year on average. The shorter the technology development cycle, the greater the chance of catch-up.
- Fluidity of technological trajectories: Defined as the degree of unpredictability of technological developments. The higher the predictability, the lower the fluidity. In such a situation, large firms are more likely to succeed. Conversely, the greater the fluidity, the greater the chance of success for small firms.
- Access to foreign knowledge: Defined as the level of access to foreign knowledge and R&D. Access to foreign knowledge sources facilitates the path of catch-up.
- Modularity: Refers to the degree of standardization of the design, construction, and assembly of subsystems of a technology. The more standardized these systems are, the higher the degree of modularity and the simpler the catch-up (e.g., mobile phones).
- Tacit knowledge: The higher the level of tacit knowledge (as opposed to explicit knowledge), the more difficult the catch-up process becomes (e.g., the automotive industry).

After reviewing more than 76 research articles on technology catch-up since the early 1990s, Miao et al. (2018) introduced two pillars of internal and external factors. While external factors consist of institutional environment and technology regime, internal factors comprise technological capabilities, catch-up strategy, dynamics and catch-up stages, and other organizational factors (Figure 4).

By comparing Miao et al.'s model with that of Lee et al. (2017), one can detect similarities, as both seek to model the catch-up process at the innovation system level (in contrast to Hobday's model, which focuses on the development of firm capabilities). One distinctive feature of Miao et al.'s model is its special attention to the creation of technological capacity (as one component of the internal factors pillar). It recommends measures such as improving absorptive capacity, local innovation, foreign technology transfer, reverse engineering, forward engineering, mergers and acquisitions, FDI, and informal training.

To conclude, existing models either focus narrowly on firm-level processes (Hobday) or national systems (Lee et al.), but none systematically integrate institutional, technological, firm, and strategic factors into a single operational framework for policymakers. This paper addresses that gap.

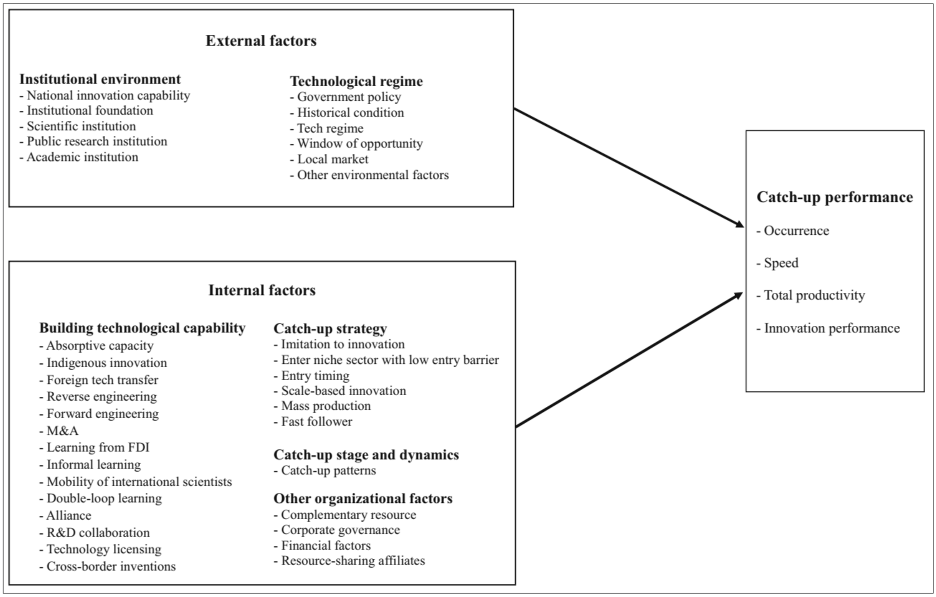



**Figure 4- Miao et al. model of technology catch-up (Miao et al., 2018)**

## 2-3- Recent Developments in the Catch-Up Literature

Post-2020 research reinforces and extends the earlier catch-up literature in three important directions. First, the role of technology cycle time has been reconsidered at micro, meso, and macro levels. Lee (2024) argues that short technology cycles can create entry opportunities for latecomers because incumbent technologies become obsolete more quickly, but the same short cycles can also limit learning time; therefore, short-cycle sectors are beneficial only when latecomers possess sufficient absorptive capacity. Chang et al. (2024) similarly show that latecomers need a changing balance between imitation and innovation: imitation is more valuable at earlier stages, whereas innovation becomes increasingly important as capabilities accumulate.

Second, digital transformation has become an important mechanism of contemporary catch-up. Recent empirical research finds that digital technology adoption can improve technological and market catch-up through dynamic capabilities, while other research shows that digital transformation works as a conditional catalyst by strengthening absorptive capacity rather than as an automatic source of productivity growth. These findings reinforce the argument that technology adoption must be combined with firm capabilities, skills, organizational change, and learning mechanisms.

Third, the green transition is creating new "windows of opportunity" for latecomers. Recent research emphasizes green technological diversification, renewable-energy value chains, and the interaction between digitalization and decarbonization. UNCTAD argues that green and digital transitions increasingly overlap in global value chains and that latecomer countries need digital competencies, financial support, and international partnerships to benefit from the twin transition. Whitfield and Wuttke (2025) further emphasize that access to foreign knowledge, domestic learning and innovation, market demand, finance, and targeted industrial policy must operate together if latecomers are to exploit emerging green opportunities.

The post-pandemic restructuring of global value chains also changes the context of catch-up. Digitalization, resilience concerns, economic nationalism, and geopolitical fragmentation are reshaping investment and production networks. For latecomers, this creates both risks and opportunities: participation in value chains can provide access to knowledge and technology, but countries must develop domestic productive capabilities and reduce excessive dependence on a narrow range of imported technologies or commodities. These developments strengthen the case for integrating trade policy into a catch-up framework rather than treating trade as an external condition.

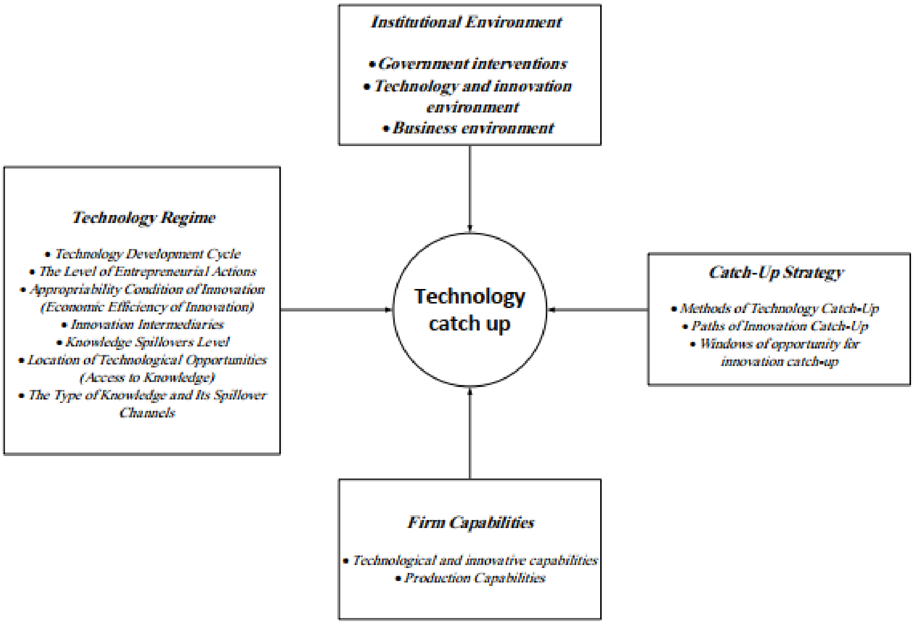
For Iran, these developments are particularly relevant because the country's catch-up process combines substantial scientific and engineering capacity with institutional constraints, sanctions-related barriers to technology and finance, and uneven firm-level capabilities. The recent Iranian literature provides evidence that technological learning can occur through domestic engineering capabilities, public procurement, technology licensing, learning-by-doing, and supplier development, while also showing the importance of international connections for sustained upgrading.

The proposed framework should be understood as an integrative synthesis rather than a claim that each individual component is entirely new. Its novelty lies in combining the four dimensions into one operational diagnostic architecture and linking them explicitly to sector selection, firm capability development, catch-up strategy, and trade policy. Table 4 summarizes this distinction.

| Framework | Primary level | Main emphasis | Institutional environment | Technology regime | Firm capabilities | Catch-up strategy | Policy/ trade linkage |
|---|---|---|---|---|---|---|---|
| Hobday (1995) | Firm | Learning path from production to design and R&D | Limited | Limited | Strong | Implicit | Limited |
| Lee & Lim (2001); Lee (2005, 2019) | Firm/ sector | Technological regimes, leapfrogging, windows of opportunity | Moderate | Strong | Moderate | Strong | Moderate |
| Lee et al. (2017) | Sector/ system | Government role, technology regime, competitive advantage | Strong | Strong | Moderate | Moderate | Moderate |
| Miao et al. (2018) | System + firm | External and internal determinants of catch-up | Strong | Strong | Strong | Strong | Moderate |
| Proposed framework | Multi-level | Integrated diagnosis and policy sequencing | Strong | Strong | Strong | Strong | Explicit |

## 3- Proposed Model of Technology Catch-Up in Developing Countries

This section provides a deeper explanation of the proposed model, including factors affecting technology and innovation. It establishes a bridge between strategies and programs for technology development, given the necessity of customizing programs for each sector according to innovation promotion components. The design of policy tools and packages in the form of a multi-level ladder model requires knowledge of the variables and factors affecting the innovation promotion system. These factors can be divided into four components: institutional environment, technology regime, firm capabilities, and catch-up strategy (Figure 5).




Source: Authors' synthesis based on the literature reviewed in this study.

**Figure 5-Proposed framework for technological catch up**

The proposed framework is explained in greater detail below.

## 3-1- Institutional Environment

The institutional environment includes institutions, innovation capabilities at the national level, and the role and performance of the government in creating them. For example, the catch-up processes of countries such as Korea, Taiwan, and China show that these countries strengthened the institutional foundations of their national innovation systems and targeted specific sectors. The role of actors in technology development is also important.

### 3-1-1- Government interventions

As mentioned, the technology development process may face failures that market mechanisms are unable to resolve. This necessitates targeted government interventions. In the technology development literature, there is consistent emphasis on the national innovation system and the role of government in facilitating and encouraging technological activities.

### 3-1-2- Technology and innovation environment

Technology development and innovation require a favorable environment for the presence of actors and stakeholders. This environment includes various infrastructures, training and skill enhancement, intellectual property protection, value creation for researchers, networking among actors, and related factors., all of which encourage firms to develop technology and innovation.

### 3-1-3- Business environment

The business environment is the collection of all endogenous and exogenous factors at the macro and sector levels that have a direct and indirect impact on firms. These factors include labor force and its characteristics (skill level, wage level, and related factors.), customers and their characteristics (expectations, purchasing power, and related factors.), market conditions and competitors, technological and social trends, economic and political developments, macroeconomic conditions, and government interventions.

## 3-2- Technology Regime

The technology regime entails creating exogenous opportunities for firms to choose appropriate technology fields. This means creating institutional and sectoral systems for innovation and technology in various industries. The environmental and institutional setup is affected by programs and policies implemented by the government, as well as the nature and characteristics of the industry and related technologies. These can be listed as follows:

### 3-2-1- Technology Development Cycle

The technology development cycle can be classified according to the stages of the product life cycle into four stages: introduction, growth, maturity, and decline. Some technologies have a long-life cycle, others a short life cycle. According to Lee (2019), technology catch-up for developing countries is associated with greater simplicity in technologies with shorter life cycles (the first level of the three-level model).

Based on this perspective, the transition strategy of developing countries should focus on choosing sectors with short-cycle technologies rather than sectors with long-cycle technologies dominated by advanced countries. Lee argues that, in contrast to the idea of comparative advantage (trade-based specialization) initially determined by resource endowments, dynamic comparative advantage in technology (technological specialization) is based on R&D capabilities acquired over time.

According to Yanfei et al., (2020)'s model, technology development follows an inverted S-curve, consisting of two stages: engineering problem-solving and scientific problem-solving. In each stage, two strategies can be adopted: access to knowledge (engineering stage) and appropriation of knowledge (scientific stage). In the access-to-knowledge strategy, the focus is on the technology demand side; in the appropriation-of-knowledge strategy, the focus is on the technology supply side.

In conclusion, according to the technology life cycle component, technology development policies can be classified into three levels. The first level focuses on developing labor-intensive technologies with a short life cycle. The main approach is access to technology, focusing on its demand side (market side). The second level targets the development of engineering technologies (after mastering basic technologies). At this stage, mastery of technologies with short and medium life cycles and accumulation of knowledge, experience, and skills are considered. The third level pursues the development of high-tech and analytical technologies with a long-life cycle. This level entails the scientific development of technology, characterized by a high degree of value added and performance relative to the amount of spending allocated to technology.

From a regulatory and legal perspective, adopting an access-to-knowledge strategy (focusing on technology demand) versus an appropriation-of-knowledge strategy (focusing on technology supply) directly influences the direction of intellectual property rights policies. As shown in Figure 6, the degree of stringency in protecting patents can vary depending on the combination of these two approaches (Lee, 2019).

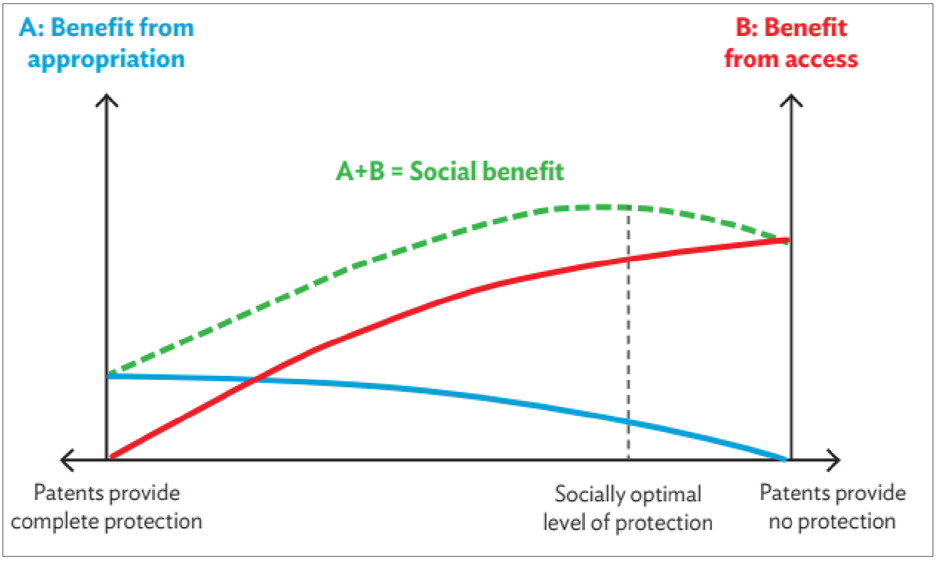



**Figure 6- Conflict between the interests of appropriation and access to knowledge and technology (Ambashi, 2017)**

### 3-2-2- The Level of Entrepreneurial Actions

Alongside technology development, entrepreneurship is often a necessary tool for technology convergence and improving the degree of innovation in a given sector (Yanfei & Zhang's model). When there is high demand for entrepreneurial actions in a field of activity, a set of policies supporting entrepreneurship must be devised.

In such situations, it is necessary to design policies and tools to support entrepreneurship in the target sector. The importance of these policies arises from the market dimension of technology integration, because mere product development does not guarantee market success. The development of start-ups and spin-off companies is one method of developing entrepreneurial services. Within the three-level model of technology development, as technologies mature and become more specific, the level of entrepreneurial actions increases. Therefore, as the innovation system improves in efficiency and moves from the first level to higher levels, supporting the creation of start-up companies should be considered. At the second level, supporting the creation of start-ups and the formation of innovation clusters among SMEs is targeted; at the third level, networking these start-ups with large companies becomes a policy objective (Yanfei, Qiang & Zhang, 2020).

### 3-2-3- Appropriability Condition of Innovation (Economic Efficiency of Innovation)

In the literature on the economic benefits of innovation and R&D, two types of benefits are considered: private benefits for the company and public benefits for society. Innovation has economic justification when private interests override public interests. However, in some industries, private interests do not justify R&D costs (public interests override private ones), for example, technologies with general and multiple applications, such as transistor manufacturing.

Moreover, because intellectual property laws do not have the same effect on innovators' rights across different industries, and some industries, such as biotechnology, inherently make it difficult for latecomers to enter and imitate while benefiting more from strong property rights, regulation of intellectual property protection laws is necessary to balance public and private interests in R&D.

Within the three-level model, at the first level, the government's focus should be on supporting development projects with the greatest benefits for the private sector. Support for development projects with a public aspect should be pursued at higher levels. Also, due to the cost-benefit justification of technology development from the demand side, at the first level the priority for R&D activities should be the development of technologies for which there is actual demand.

**Table 2- Types of government interventions according to the private and public costs of research and development**

| Private interests in research and development | | | |
|---|---|---|---|
| high | low | | |
| Minimum government incentive | Maximum government incentive | high | public interest in research and development |
| Failure to provide incentives or even levy taxes | choice of alternative technology | low | |

### 3-2-4- Innovation Intermediaries

Innovation intermediaries are components that connect the innovation system's actors, such as universities, companies, and related factors., in situations where these actors would otherwise act independently and in isolation, leading to suboptimal outcomes. The most important functions of these intermediaries are providing financing, equipment, technology, and market access to components of the innovation system. In the three-level model, at the first level, the government focuses on technologies that are less dependent on innovation intermediaries. At the second and third levels, the presence and role of innovation intermediaries become more important within national and sectoral innovation systems.

### 3-2-5- Knowledge Spillovers Level

Some technologies have a low level of knowledge spillover; their development can be used only in a few industries. Others have a high level of knowledge spillover; their development benefits a wide range of industries. Given constraints such as financial resources and time, investment priority should be given to technologies with high spillover potential, and special tools and support should be considered for this category of technologies.

### 3-2-6- Location of Technological Opportunities (Access to Knowledge)

The development and completion of some technologies require the interaction of multiple stakeholders. Internal R&D activities are not the only source of tangible technological and innovative outcomes. Technology development is not possible based solely on a company's internal resources; opportunities outside organizations can also be used, such as customer feedback, better inputs from suppliers, reverse engineering of competitors' products, and related factors. Different industries rely on different external sources, and the intensity of this reliance varies. For example, the pharmaceutical industry has a higher dependence on external sources (links with universities) as an industry based on analytical knowledge.

Industries where most technological opportunities are located in sources outside the firm's direct field of activity require special tools for networking actors to synergize activities along the cooperation path. Their technology development is more complex.

### 3-2-7- The Type of Knowledge and Its Spillover Channels

Knowledge spillover channels affect the nature of innovation policy. Spillover channels are sources of knowledge acquisition for technology development. To identify these sources, it is first necessary to present a classification based on industrial knowledge. The knowledge base for technology development and innovation can be divided into three types: analytical knowledge, engineering knowledge (synthetic), and symbolic knowledge. The key component of this framework is the degree of tacit knowledge involved and the level and type of communication between knowledge sources and the firm (the more tacit the knowledge, the lower the chance of its transfer).

Within the three-level model for technology development and innovation, at the first level, due to the ease of knowledge transfer, it is necessary to focus on industries centered on engineering (synthetic) and symbolic knowledge. At subsequent levels, as the technology system develops and matures, a focus on knowledge spillover channels based on analytical knowledge is recommended.

## 3-3- Firm Capabilities

### 3-3-1-Technological and innovative capabilities

Along with the institutional environment (first factor) and technology regime (second factor), the internal capabilities of the firm, such as organizational and managerial capabilities, are important for the successful management of technological and innovative projects.

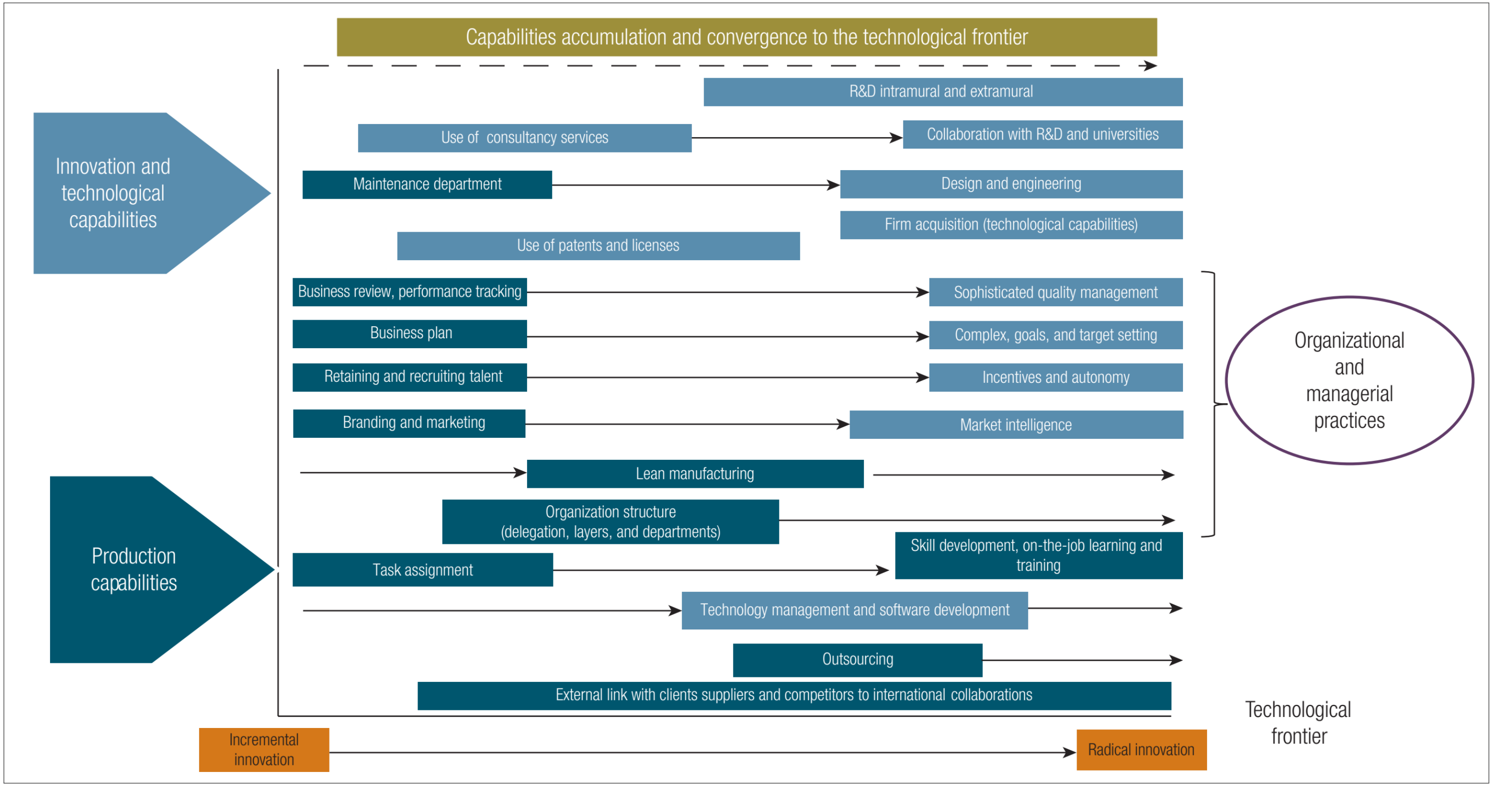
From another perspective, technological capabilities within the firm refer to a set of actions the company takes to increase its ability to develop technology. These actions include the capacity to attract, identify, and take advantage of knowledge and technology spillovers, internal R&D, and skilled labor.

To improve technological capabilities within the firm, it is important to design learning channels, which include production based on assembly, learning through export, internal or external joint R&D, collaborative R&D, transfer of expert labor, mergers and acquisitions, and related factors.

### 3-3-2- Production Capabilities

Production capabilities also rely on the firm's managerial, technical, and financial capabilities. Correct execution of business processes and activities, technical knowledge and skills necessary for developing capabilities, and a solid financial base are among the factors a firm needs to invest in on the path to technology catch-up.

Figure 7 shows some of these organizational capabilities (including technological, innovative, and production capabilities). Many of them are basic capabilities that develop and reach more complex levels as the firm moves toward innovation. As the firm progresses (moving from left to right in the figure), the catch-up process of technology development and innovation begins and moves from adaptation to basic technologies to high levels of R&D and innovation.




Source: Xavier Cirera, instruments to Build Firm Capabilities and Accelerate Technological Catch-Up in Developing Countries, world bank group, 2020.

**Figure 7- The development path of firm capabilities**

Although the types and degrees of these capabilities vary by sector, having some basic capabilities is necessary for any firm on the path to innovation development. The technology development paths of countries such as Japan, Singapore, China, and Taiwan show that the development of these capabilities has played an essential role in technological learning and facilitating innovation development.

## 3-4- Catch-Up Strategy

Choosing the appropriate catch-up and technology development strategy, as well as identifying upcoming windows of opportunity, constitutes the fourth component affecting the catch-up process. It should be noted that, contrary to common belief, these strategies must arise from within the firm and cannot be assigned by the government or policymakers.

### 3-4-1- Methods of Technology Catch-Up (Development).

Technology development and catch-up require adopting correct strategies within the firm to leverage resources and make the most of opportunities. These strategies depend on the firm, its level of capabilities, and the nature of each field of activity. Three strategies can be considered (Lee & Lim, 2001):

#### I. Path Following Catching Up

In this method, new entrants follow the path of pioneer companies. This method includes a completely imitative pattern of technology acquisition. Reverse engineering is one of the most important methods in this category. Generally, this method cannot bring sustainable success for new firms, and some degree of technological leap is required. This strategy has been used by most home appliance manufacturing companies.

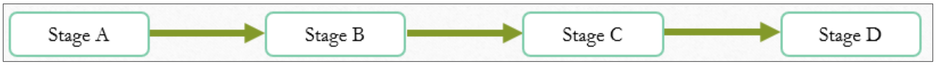



**Figure 8- Path Following Catching Up**

#### II. Path Skipping Catching Up

In this method, new entrants follow some stages of the path taken by leading companies while skipping others (Type 1 skip). This method involves creativity in the technology acquisition path. The development of car engine technology and digital phone technology are examples.

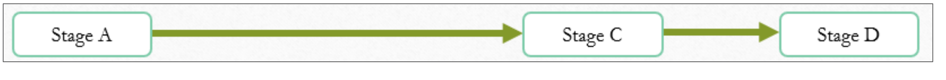



**Figure 9- Path skipping catching up**

### III. Path Creating Catching Up

In this method, after initially following the path of pioneer firms, new entrants shift toward a new path, thereby creating a new trajectory (Type 2 skip). This method involves innovation in technology acquisition (integration of technology and innovation). Technological skips require windows of opportunity. Changes in technology generations, market conditions, and related factors., can provide such opportunities for a firm or industry. The production of smart equipment is an example. In Figure 10, steps C’ and D’ represent competing technologies for C and D.

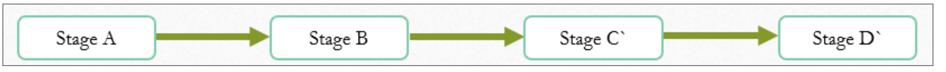



**Figure 10- Path creating catching up**

It is important to note that technology catch-up with leading countries is initially achieved through path-following, but eventually skipping (either path-skipping or path-creating) becomes necessary (Lee, 2005).

### 3-4-2- Paths of Innovation Catch-Up

The process of catch-up specifically refers to three stages of development: OEM (original equipment manufacturing), ODM (original design manufacturing), and OBM (original brand manufacturing). OEM is a kind of simple imitation, ODM is creative imitation, and OBM refers to genuine innovation. While the first two stages are path-following catch-up, the third stage includes path-skipping and path-creating catch-up (leadership in technology).

If the path from OEM to OBM into four stages, (1) skill development, (2) process technology development, (3) product design technology development, and (4) new product development, moving from stage 2 to stage 3 is very difficult, as it requires design capabilities, R&D, and production of products with higher added value to compete with technology leaders.

It should also be noted that catch-up through OEM is labor-intensive. If leading firms move toward low-wage countries, it becomes difficult to compete. In such circumstances, countries may remain at the OEM level with a limited domestic market.

Table 3. Paths of Innovation Catch-Up (Lee, 2019)

| Stages of Catch-up | Step 1: Repetitive imitation (OEM) | Step 2: Repetitive imitation (OEM) | Stage 3: Creative Imitation (OBM in South Korea and ODM in Taiwan) | Stage 4: True Innovation |
|---|---|---|---|---|
| Catch-up Method | Path Following | Path Following, Path Skipping | Path Skipping | Path creating |
| focus of learning | Operational Skills | Process Technology | Design Technology | New Product Development Technology |
| learning mechanism | learning-by-doing and using the instruction manuals | learning-by-doing and trying to design a product | domestic research and development, joint and open | Strategic alliances and joint development |

### 3-4-3- Windows of opportunity for innovation catch-up

In technology catch-up, identifying and leveraging windows of opportunity is very important. These opportunities help latecomers reduce their technology gap with leading firms. Latecomers face certain advantages, such as opportunities to leverage resources, reduce time to access knowledge, and transfer technology and learning, but also face challenges such as low profit margins and mass production and sales. Windows of opportunity can be listed as follows:

#### I. Technology Transformation

Technological transformation creates an opportunity for latecomers to start from a starting point relatively close to that of advanced countries (even leading firms may be reluctant to move along a new technology path).

#### II. Market Conditions

Market conditions provide another window of opportunity. For example, a high market share for a product, market segmentation, the emergence of new customer combinations, or presence in sectors that competitors do not want to enter can serve as windows of opportunity for technology catch-up.

#### III. Changes In Public Institutions and Policies

Changes and developments in the institutional structure or the legal and regulatory environment can spark entrepreneurship, the creation of new enterprises, and capital attraction in productive sectors. Therefore, any changes in institutional structure and policies also represent significant windows of opportunity for technology development.

#### IV. Low Price Advantage

The ability of an industry or firm to produce low-cost products is another window of opportunity for technological leap, given its impact on the costs of upgrading technology.

## 4- Iran-Specific Application of the Framework

The four-pillar framework is particularly useful for Iran because the country's technological position is characterized by a combination of substantial scientific and engineering resources, significant domestic industrial capacity, strong market size, and persistent constraints on international technology, finance, and trade. The Global Innovation Index placed Iran 70th in 2025 and identifies the country as an innovation-output overperformer relative to its input level, while also showing substantial weaknesses in institutional and business conditions. The 2024 GII reported particularly weak rankings for Iran in institutional environment, regulatory environment, and business environment. These indicators should be interpreted cautiously because WIPO's statistical audit reports a relatively wide confidence interval for Iran's 2024 rank.

### 4-1- Institutional Environment

Iran's institutional environment presents a mixed picture. On the positive side, the country has a large science and engineering base, established universities and research institutions, science and technology parks, and a policy tradition that explicitly recognizes technological capability and innovation. Recent Iranian research on the Ministry of Science, Research and Technology argues, however, that the multiplicity of policy instruments and institutional responsibilities has not translated into consistently favorable innovation-system performance. A demand-oriented study of science and technology parks likewise suggests that Iranian innovation policy can benefit from shifting beyond purely supply-side support toward demand-oriented instruments.

The external institutional environment is also shaped by sanctions. EU restrictive measures include constraints on energy trade, investment, equipment, financial and business services, and selected technology and dual-use goods. These restrictions increase transaction costs, limit technology sourcing and finance, and make international partnerships more difficult. Iranian industrial research also indicates that sanctions have contributed to structural shifts toward food, chemicals, steel and minerals, while machinery and automobile production, sectors more dependent on foreign technology, partnerships and imported intermediate goods, have been particularly constrained.

Policy implication: Iran should treat institutional reform as an enabling condition for catch-up rather than merely an administrative objective. Priority reforms should include stable sectoral technology strategies, transparent criteria for public R&D and procurement support, stronger coordination among the Ministry of Science, Research and Technology (MSRT), Ministry of Industry, Mine and Trade (MIMT), Ministry of Economic Affairs and Finance, National Development Fund, Central Bank, and relevant sector regulators, and mechanisms that reward firms for measurable learning and export performance. Because sanctions cannot be removed by domestic innovation policy alone, the institutional pillar should also include lawful and transparent channels for international scientific cooperation, technology licensing, standards cooperation, and regional trade relationships.

## 4-2- Technology Regime in Iran

Iran's technology regime is heterogeneous. It includes mature resource-based and process industries such as oil and gas, petrochemicals, steel, cement and mining; medium-technology manufacturing such as automotive and machinery; and emerging technology-intensive activities in pharmaceuticals, biotechnology, ICT and selected engineering services. The appropriate catch-up strategy therefore cannot be uniform across sectors. The 2024 Iranian steel case study provides a concrete example: technological learning has involved learning-by-doing, engineering-company development, supplier capability building, R&D, licensing, joint manufacturing and international connections, while public procurement, financing and institutional policy have helped create windows of opportunity.

The framework suggests that Iran should prioritize sectors where domestic capabilities and market demand can be combined with realistic opportunities for technological upgrading. Candidate priorities include selected steel and mining equipment, petrochemical downstream products, pharmaceuticals and biotechnology, industrial machinery, agricultural technologies, digital services, renewable-energy equipment and energy-efficiency technologies. The selection should be based on technology-cycle time, modularity, domestic demand, export potential, knowledge spillovers, dependence on imported critical inputs, and the feasibility of building local engineering and supplier capabilities.

## 4-3- Firm Capabilities

Iranian firms display substantial variation in technological and absorptive capabilities. Some large manufacturing and engineering organizations have accumulated significant production and process capabilities, while many firms remain dependent on imported equipment, components, software, licenses, or foreign technical knowledge. The Iranian steel evidence illustrates how firms can move beyond simple acquisition by developing engineering subsidiaries, supplier networks, R&D activities and learning-by-doing. Conversely, the literature on sanctions indicates that sectors heavily dependent on imported technology and foreign partnerships have faced greater disruption.

The policy objective should therefore be to move firms from operational competence toward engineering, design, product development and eventually original innovation. Support should be conditional on capability accumulation: firms receiving public incentives should demonstrate training, engineering localization, supplier development, quality certification, R&D projects, technology adaptation, export learning, or measurable reductions in critical import dependence. Digital transformation should be treated as part of this capability-building process rather than as a stand-alone technology purchase.

## 4-4- Current and Emerging Catch-Up Strategies

Iran's experience contains elements of import substitution, domestic capability building, public procurement, technology licensing, reverse engineering, supplier development, and export-oriented activity in selected sectors. Sanctions have also created a form of forced localization in some industries. However, import substitution by itself can protect firms without generating international competitiveness. The framework therefore recommends a transition from defensive import substitution toward “capability-conditional import substitution”: temporary protection should be linked to productivity, localization of critical technologies, quality improvement, export performance, and movement from OEM-like production toward design and branded products.

Export promotion should complement rather than replace import substitution. Firms should be encouraged to use regional markets as learning platforms, especially where Iran has geographic or cost advantages. The strategic objective is to use protected or domestic demand to accumulate capabilities and then expose firms progressively to international standards, competition, and demanding customers.

## 4-5- Illustrative Case Study: Iran’s Steel Industry

Iran’s steel industry provides an illustrative application of the four-pillar framework. Attarpour, Elyasi and Mohammadi (2023) used a mixed-method case study and DEMATEL analysis to examine windows of technological learning in Iranian steel. Their findings identify institutional, demand and technology opportunities and emphasize the roles of public planning, investment, financing, public procurement and empowerment policies. At the firm level, learning-by-doing, technical-engineering companies, supplier development, R&D, technology licensing and joint manufacturing were important mechanisms. The study also identifies international relationships, constrained by sanctions, as a highly influential factor in technological learning.

Mapped onto the proposed framework, the case shows: (1) institutional environment, government planning, financing, and procurement; (2) technology regime, steel process technologies and equipment opportunities; (3) firm capabilities, engineering, suppliers, R&D and learning-by-doing; and (4) catch-up strategy, technology acquisition followed by adaptation, localization and innovation. The case therefore illustrates the central proposition of this paper: catch-up is more likely when policy support, technological opportunity, firm learning and strategy reinforce one another.

## 4-6- Comparative Benchmark: Iran and Türkiye

Tьrkiye provides a useful benchmark because it is a regional middle-income economy with a more deeply integrated manufacturing and export base and a substantially higher innovation ranking. WIPO’s 2025 GII ranks Tьrkiye 43rd and Iran 70th. Tьrkiye also ranks 35th in innovation outputs and 49th in inputs, while Iran’s overall position remains constrained by weaker institutional and business conditions. The comparison should not be interpreted as a simple policy-transfer exercise: the countries differ in geopolitical position, sanctions exposure, market institutions, industrial structure and external integration.

The comparison nevertheless yields a useful strategic lesson. Tьrkiye’s experience illustrates the importance of combining domestic firm capabilities with international market integration, export-oriented manufacturing, technology adoption and participation in regional/global production networks. For Iran, the relevant lesson is not to copy Turkish institutions wholesale, but to identify the functions that support upgrading, stable industrial priorities, export discipline, supplier development, technology adoption, international standards, and firm-level learning, and reproduce those functions within Iran’s own constraints.

## 5- Trade Policy Integration

Trade policy is an integral part of technological catch-up because access to imported capital goods and knowledge, exposure to international competition, and participation in global value chains affect both the technology regime and firm capabilities. World Bank research emphasizes that firms can learn from multinational enterprises through investment, partnerships and trade, while UNCTAD stresses that reducing trade costs, improving market access and moving into higher-value activities can support diversification and technological upgrading. For Iran, however, trade policy must be designed under sanctions and financial constraints, making regional and neighboring markets especially important.

### 5-1- Import Substitution

Import substitution should be selective and temporary rather than economy-wide. Priority should be given to imported technologies or components that are strategically important, have strong domestic demand, generate spillovers, and can realistically be localized. Tariff or procurement support should be linked to explicit capability targets and sunset clauses. Protection without productivity, quality and export conditions risks creating low-productivity incumbents rather than catch-up firms.

### 5-2- Export Promotion

Export promotion should focus on products and services where Iran can build differentiated capabilities rather than merely compete on low prices. Export support can include standards certification, export finance, market intelligence, logistics facilitation, digital trade infrastructure, regional trade missions and support for firms entering demanding neighboring markets. Export performance should become a criterion for continued industrial support because international competition provides a mechanism for testing whether technological upgrading has generated genuine competitiveness.

### 5-3- Global Value-Chain Participation

Iran should pursue GVC participation through realistic regional entry points rather than attempting immediate integration into every global industry. Priority should be given to value chains in which

Iran possesses existing productive assets and can move toward higher-value tasks: petrochemical derivatives and specialty chemicals, steel and engineering services, pharmaceuticals, food processing, agricultural technologies, ICT services, and selected renewable-energy and energy-efficiency products. The goal should be progression from assembly and basic processing toward design, engineering, component production, certification, and branding.

## 5-4- Trade Agreements and Regional Integration

Regional trade agreements and trade facilitation can partly offset the constraints created by restricted access to major financial and technology markets. Iran should prioritize predictable customs procedures, standards harmonization, digital trade documentation, logistics corridors, and deeper commercial relationships with neighboring and regional economies. Trade diplomacy should be coordinated with industrial policy so that negotiated market access is linked to sectors in which domestic firms are capable of supplying competitively.

The following policy package translates the framework into implementable priorities. The sequencing is deliberate: institutional and information reforms should precede large-scale subsidies; capability-building should be linked to technology selection; and export discipline should increase as firms mature.

| Pillar | Priority policy | Target sectors/ actors | Lead institutions | Resources / instrument | Key outcome |
|---|---|---|---|---|---|
| Institutional environment | Create a cross-ministerial Catch-Up Council and sector roadmaps with 3–5 year targets | Priority manufacturing, digital and green sectors | MIMT, MSRT, Ministry of Economy, NDFI, Central Bank | Coordination budget; shared data platform; competitive grants | Stable priorities; fewer overlapping instruments |
| Institutional environment | Use demand-side innovation policy and competitive public procurement | Energy, health, ICT, industrial equipment | MIMT, MSRT, sector ministries and state buyers | Procurement quotas/ competitions linked to performance | Domestic lead markets for innovative firms |
| Technology regime | Select sectors using cycle time, modularity, spillovers, demand and import dependence | Steel equipment, pharma, machinery, ICT, renewables | MIMT + sector agencies | Sector diagnostics; technology roadmaps | Concentrated resources in feasible windows |
| Firm capabilities | Capability grants conditional on training, engineering, quality, R&D and localization | SMEs and large anchor firms | MIMT, MSRT, Innovation Fund | Matching grants, vouchers, supplier-development funds | Higher absorptive and engineering capacity |
| Firm capabilities | Digital transformation tied to organizational upgrading | Manufacturing SMEs and exporters | MIMT, ICT Ministry, Innovation Fund | Digital vouchers, shared testbeds, skills programs | Productivity and data-enabled production |

| Pillar | Priority policy | Target sectors/ actors | Lead institutions | Resources / instrument | Key outcome |
|---|---|---|---|---|---|
| Catch-up strategy | Shift from protected import substitution to capability-conditional upgrading | Automotive, machinery, chemicals, steel | MIMT, trade agencies | Sunset tariffs + export/ productivity milestones | Higher-quality domestic production |
| Catch-up strategy | Use regional exports as learning platforms | Pharma, food, engineering, ICT, petrochemical derivatives | Trade authorities, MIMT, firms | Export finance, certification, market intelligence | Export diversification |
| Trade policy | Facilitate regional GVC participation and technology partnerships | Neighboring-market value chains | Foreign Affairs, MIMT, customs, trade bodies | Trade facilitation, standards, logistics agreements | Higher-value GVC tasks |
| Green transition | Create green windows of opportunity with procurement and finance | Renewables, efficiency, water, low-carbon equipment | Energy Ministry, Environment, MIMT, MSRT | Green procurement, concessional finance, pilot markets | Green capability accumulation |

## 6- Catch-Up Readiness Diagnostic

To operationalize the framework, policymakers can assess each sector or industrial cluster using a four-pillar readiness score. The purpose is not to produce a mechanically "correct" ranking but to make assumptions explicit and identify the weakest binding constraints. Scores should be based on sector-level data and reviewed annually.

### 6-1- Scoring System

| Pillar | Indicator examples | Suggested weight | Score (0–5) | Interpretation |
|---|---|---|---|---|
| Institutional environment | Policy stability; regulatory quality; infrastructure; finance access; quality of public support; international access | 25% | 0–5 | 0 = severe constraint; 5 = strong enabling environment |
| Technology regime | Technology cycle time; modularity; knowledge spillovers; appropriability; import dependence; market demand | 25% | 0–5 | 0 = poor catch-up window; 5 = strong opportunity |
| Firm capabilities | Absorptive capacity; engineering skills; production quality; R&D; supplier capability; digital maturity | 25% | 0–5 | 0 = insufficient capability; 5 = strong capability base |
| Catch-up strategy | Clear pathway; technology acquisition; learning mechanism; export orientation; windows of opportunity | 25% | 0–5 | 0 = absent/incoherent; 5 = coherent and executable |

Overall readiness score = 0.25(I) + 0.25(T) + 0.25(F) + 0.25(S), where I, T, F and S are the 0–5 scores for institutional environment, technology regime, firm capabilities and catch-up strategy. A score below 2.0 indicates that catch-up should not yet be the subject of large-scale sectoral investment without first addressing binding constraints. A score of 2.0–2.9 indicates an emerging opportunity requiring targeted capability and institutional support. A score of 3.0–3.9 indicates a viable catch-up sector suitable for coordinated upgrading programs. A score of 4.0–5.0 indicates a strong candidate for scale-up, export promotion and movement toward higher-value innovation. These thresholds are proposed analytical rules, not empirically validated cut-offs.

A second rule should prevent high readiness in one pillar from concealing a critical weakness in another. Policymakers should therefore also apply a "minimum-pillar" test: if any pillar scores below 2, the sector should receive diagnostic and capability-building support before major scale-up. This avoids a one-size-fits-all interpretation of the framework and makes customization explicit at the sector level.

## 7- Conclusion and Limitations

This paper develops an integrative framework for technological catch-up in latecomer economies organized around four interconnected pillars: institutional environment, technology regime, firm capabilities, and catch-up strategy. The contribution is not the invention of four entirely new categories; rather, it lies in integrating dimensions that are often examined separately and converting them into a multi-level diagnostic and policy architecture. The framework connects macro institutions and trade conditions with sectoral technology characteristics and micro-level capability accumulation.

The Iran-specific application shows why such integration matters. Iran possesses substantial scientific and industrial assets and demonstrates innovation outputs that are stronger than its input position would suggest, yet institutional weaknesses, sanctions-related restrictions, uneven firm capabilities, and limited international integration constrain the conversion of these assets into broad-based technological upgrading. The steel case illustrates that progress is possible when public procurement, finance, engineering capabilities, supplier development, learning-by-doing and international technological connections reinforce each other.

The policy implication is a move from generic support toward sequenced, sector-specific capability building. Iran should prioritize sectors with realistic technological windows, combine selective and temporary import substitution with export discipline, use regional markets as learning platforms, strengthen firm-level absorptive and engineering capabilities, and integrate digital and green transitions into industrial policy. Trade policy should be treated as a component of catch-up because access to markets, technologies, inputs, standards and value chains affects both the technology regime and firm learning.

### 7-1- Limitations and Applicability Boundaries

The framework has several limitations. First, it remains conceptual and has not been empirically validated through a large-N data set, Delphi exercise, or systematic expert survey. The Iranian case evidence used here is secondary evidence from published studies rather than primary interviews conducted by the authors. Second, the proposed readiness scores and thresholds are analytical tools rather than empirically calibrated measures. Future research should test their predictive validity across sectors and countries.

Third, the framework is not intended as a one-size-fits-all policy prescription. Its four pillars are deliberately broad, while their indicators, weights, and policy instruments must be customized to sector characteristics, technology maturity, firm size, institutional capacity, and geopolitical constraints. A policy that is appropriate for steel may be inappropriate for pharmaceuticals or digital services. Fourth, sanctions and international political economy conditions can alter the feasible set of technology and trade options faster than domestic policy can respond; the framework should therefore be updated periodically.

Future research should undertake comparative sectoral applications in Iran and peer economies, undertake expert Delphi validation, estimate the relationship between pillar scores and catch-up outcomes, and test whether the proposed sequencing improves productivity, export sophistication, technological localization and innovation performance. Such work would convert the framework from a conceptual diagnostic into an empirically validated policy instrument.

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