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MAIN OBJECTIVES OF THE JOURNAL OF TRADE AND INDUSTRIAL POLICIES

1. Advancing and Disseminating Specialized Knowledge in Industrial, Mining, and Trade Policy
   - Publishing rigorous, research-based and policy-oriented studies
   - Focusing on real-world challenges and national development priorities
2. Bridging Research, Academia, and Policymaking
   - Connecting scientific findings and evidence with policymaking and decision-making processes.
   - Providing a platform for meaningful dialogue and interaction between researchers and policymakers.
3. Strengthening Iran's Scientific Presence in the International Arena
   - Introducing Iran's capacities, experiences, and research findings to the global academic community.
   - Establishing an English-language scholarly platform for presenting and disseminating Iranian academic perspectives.
4. Building an Academic Network among Domestic and International Researchers
   - Attracting high-quality scholarly contributions from faculty members and researchers at universities in Iran and abroad.
   - Fostering academic collaboration with universities, think tanks, and regional and international research institutions.
5. Scholarly Reflection on Iran's Industrial, Mining, and Trade Experiences and Policies
   - Transforming the country's practical and policy experiences into transferable knowledge.
   - Providing evidence-based analysis of the challenges, achievements, and policy options facing Iran's industrial, mining, and trade sectors.
6. Promoting Knowledge and Experience Exchange between Iran and the Global Community
   - Facilitating the transfer of emerging scientific and policy developments to the country's professional and academic communities.
   - Providing a forum for scholarly dialogue on global developments in trade and industry.
7. Creating a Platform for the Participation of Economic and Developmental Organizations and Stakeholders
   - Leveraging the capacities of organizations and institutions such as IDRO, IMIDRO, the Geological Survey, professional associations, industry and production organizations, and science and technology parks.
   - Promoting the scholarly documentation, analysis, and evaluation of the experiences and achievements of these organizations and institutions.
8. Advancing Technology, Innovation, and Knowledge-Based Enterprises in Industrial Development
   - Examining the role of technology and innovation in production systems and value chains.
   - Providing opportunities for knowledge-based companies to present their research, innovations, and practical experiences to the international community.
9. Exploring Iran's Position in Regional and Global Value and Supply Chains
   - Examining Iran's geopolitical, industrial, mining, and trade capacities.

- Analyzing the opportunities and challenges associated with Iran's participation in regional and global value chains and international trade.

10. Establishing the Journal as a Credible Scholarly and Policy Reference in Industry and Trade
    - Enhancing the scientific quality of published articles through rigorous peer review and engagement with reputable academic conferences and scholarly networks.
    - Building international credibility and establishing the journal as a platform for the generation, exchange, and advancement of knowledge and policy ideas in the fields of industry, mining, and trade.

SCOPE OF THE JOURNAL OF TRADE AND INDUSTRIAL POLICIES

1. Industrial Dynamics, Industrial Transformation & Technological Advancement: Analysis of industrial capacities, manufacturing excellence, the integration of Industry 4.0 in emerging markets, advancing industrial operational excellence, lean manufacturing, and data-driven process optimization to enhance national industrial competitiveness. JEL Classification:
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- Q48 (Energy Policy).
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- Q56(Environment and Development)

11. Digital Trade, E-Commerce, AI Governance & Smart ServicesScope:Research on digital trade, electronic commerce, AI-driven business models, blockchain-enabled commerce, smart logistics, digital platforms, fintech, digital governance, consumer behavior in digital markets, intelligent marketing, digital transformation, and regulatory frameworks for e-commerce and digital services. JEL Classification:

- L81 – Retail and Wholesale Trade; E-commerce
- L86 – Information and Internet Services
- O33 – Technological Change: Choices and Consequences
- F13 – Trade Policy; International Trade Organizations
- D83 – Search; Learning; Information and Knowledge
- M15 – IT Management

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Editor-in-Chief's Note

It is with great pride that I announce the publication of the inaugural issue of the journal of Trade and Industrial Policies.

Our commitment to transferring innovative and technological achievements from applied research projects into practical implementation—through meaningful and productive dialogue between academic institutions and technology enterprises—forms the core mission of this journal. We firmly believe that a bidirectional flow of knowledge between academia and industry can inform evidence-based policymaking and pave the way toward sustainable national development.

Disseminating applied findings and technological innovations in the form of scholarly English articles serves as the primary gateway for integrating domestic research into the global knowledge network and international value chains. Documenting and publishing achievements in this lingua franca maximizes research visibility, ensures international validation through rigorous peer-review processes, and prevents redundant and costly research duplication. Furthermore, standardizing indigenous innovations within the framework of scientific articles facilitates cross-border investment, international intellectual property partnerships, and the accelerated commercialization of high-tech products in global markets.

From a knowledge-based economy perspective, publishing applied research acts as a robust bridge for scientific diplomacy and reciprocal technology transfer. This mechanism not only introduces the problem-solving capabilities and technological competencies of academic institutions to the global ecosystem, but also fosters strategic synergy with premier research centers, benchmarking against international best practices, and the adoption of modern industrial standards. Ultimately, such publications provide a credible, evidence-based repository to guide informed industrial policy formulation at national, regional, and international levels, thereby reinforcing sustainable industrial growth and economic resilience.

Despite the tireless efforts of our editorial and executive teams, we recognize that perfection remains elusive. Therefore, we warmly welcome constructive feedback, insights, and recommendations from esteemed scholars, experts, and colleagues. This spirit of critical self-reflection will continue to guide our continuous improvement and elevate the scientific and industrial rigor of future issues.

Through the guidance and active collaboration of leading authorities in science, technology, and innovation—across academia, industries, and knowledge-based enterprises—we aspire to advance the mission of this journal through high-impact, purposeful contributions. Realizing this vision is impossible without the active engagement of our authors, peer reviewers, and distinguished readers.

In conclusion, I extend my profound gratitude for the visionary leadership and unwavering support of the Director-in-Charge and the Head of Institute for Trade Studies & Research (ITSR), the distinguished members of the Editorial Board, our dedicated executive team, the peer reviewers, and all contributing authors.

I look forward to the fruitful continuation of this collaboration and the enduring success of upcoming issues.

Mohammad R. Soleymani Yazdi, Ph.D.
Editor-in-Chief
Journal of Trade and Industrial Policies

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The Middle East: Challenges of Conflict and Rethinking Industrial Policy

(Opening Essay for the First Issue by Director-in-Charge)

Hossein Modarres Khiabani, Head of Institute for Trade Studies and Research (ITSR)

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Abstract

This inaugural essay marks the launch of the Journal of Trade and Industrial Policies (JTIP), positioning it as a scholarly bridge between Iran's industrial experiences and the global academic community. Drawing on four and a half decades of research at the Institute for Trade Studies and Research, this journal seeks to foster dialogue on critical development challenges. The article addresses the urgent intersection of geopolitical conflict and the necessity for industrial policy reform in the Middle East. It examines the current crisis as a multi-layered supply shock, exacerbated by disruptions in the Strait of Hormuz, which has unevenly impacted regional economies based on their structural vulnerabilities and trade dependencies. The essay argues that amidst such turbulence, "industrial policy" must transcend state-led, rent-based models. Instead, it advocates for a "Resilient Economy" paradigm, centered on internalizing value chains, fostering knowledge-based capabilities, and diversifying production. The author contends that peace and geopolitical stability are prerequisites for successful industrial transformation. Ultimately, this journal aims to provide a platform for rigorous analysis of these dynamics, offering insights into how structural resilience can be achieved to navigate the complex economic architecture of the modern Middle East.

Keywords: Industrial Policy, Natural Resource, Knowledge Base Economy

چکیده

مجله «سیاست‌های تجاری و صنعتی (JTIP)» با اتکاء به چهار دهه و نیم پژوهش و تجربه علمی در «مؤسسه مطالعات و پژوهش‌های بازرگانی»، در پی آن است که بستری برای گفت‌وگویی علمی و مستند پیرامون چالش‌های بنیادین توسعه فراهم آورد. جستار افتتاحیه حاضر، ضمن معرفی آن به عنوان پلی علمی میان تجربه‌های صنعتی ایران و جامعه دانشگاهی بین‌المللی، نظر به شرایط موجود اقتصاد ایران بر تلاقی سرنوشت‌ساز منازعات ژئوپلیتیکی و ضرورت اصلاح سیاست‌های صنعتی در خاورمیانه تمرکز کرده و در این چارچوب، بحران موجود را به مثابه یک تکانه چندلایه در طرف عرضه تحلیل می‌کند؛ تکانه‌ای که اختلال‌های ایجاد شده در تنگه هرمز بر دامنه و شدت آن افزوده و آثار آن، متناسب با میزان آسیب‌پذیری ساختاری و وابستگی‌های تجاری، در اقتصادهای منطقه به‌گونه‌ای نامتوازن بروز یافته است. این بی‌ثباتی و تلاطم گسترده، به ناگزیر مفهوم «سیاست صنعتی» را از الگوهای دولت‌محور فراتر می‌برد و بر ضرورت گذار به پارادایم «اقتصاد تاب‌آور» تاکید می‌کند؛ پارادایمی که بر درونی‌سازی زنجیره‌های ارزش، توسعه و تقویت قابلیت‌های دانش‌بنیان و تنوع‌بخشی به ساختار تولید استوار است. از دیدگاه نویسنده، صلح و ثبات ژئوپلیتیکی، پیش‌شرط‌های اساسی تحول و دگرگونی موفق حکمرانی صنعتی به شمار می‌روند. این مجله خواهد کوشید تا بستری برای تحلیل دقیق، مستند و روشمند این پویایی‌ها فراهم آورد و از این رهگذر، بینش‌هایی درباره چگونگی ایجاد تاب‌آوری ساختاری بخش صنعت و تجارت در اختیار پژوهشگران و سیاست‌گذاران قرار دهد؛ آن تاب‌آوری که بتواند اقتصادهای منطقه را برای مواجهه با معماری پیچیده و در حال تحول اقتصادی خاورمیانه جدید آماده سازد.

1. Introduction: The Legacy of Knowledge and a New Vision in Trade and Industrial Policy Research

More than four and a half decades of research activity at the Institute for Trade Studies and Research have left a fruitful legacy of knowledge production, accumulation of experience, and structural interaction with the policy-making apparatus in the fields of industry, mining, and trade. This scientific institution stands today on the shoulders of 46 years of continuous effort and, as much as it chronicles the history of the country's trade and industrial policy, it also illuminates the future horizons of this field. The publication of reputable journals such as "Trade Research," "Trade Reviews," and "Trade Policy and Development Studies" has been a part of the intellectual history of this institution and a sign of its dynamism in expanding the frontiers of knowledge. Now, the launch of the English-language Journal of Trade and Industrial Policies (JTIP) is a new step formed based on this same intellectual legacy; a long-standing will that has come to fruition today to provide a global platform for academic dialogue.

This journal is not merely a new scientific output alongside other journals; rather, it is a purposeful attempt to establish deeper communication with the regional scientific environment and the international community, a bridge between public policy and academic forums, and also between the lived industrial and trade experience of Iran and the global intellectual space. On one hand, this journal reflects the strategies, frameworks, and macro policies of the industry, mining, and trade sector, and on the other hand, it will be a platform for continuous interaction with research institutes, think tanks, and academic centers at the regional and global levels.

The presence of more than 50 prominent faculty members and researchers at the Institute for Trade Studies and Research has created an unparalleled knowledge reservoir that can serve as a repository of wisdom and a source for generating developmental thought. Today, beyond a single research arm, the Institute acts as a knowledge assistant to the government in promoting a developmental outlook on the production and exchange sectors; a capacity that is now reflected in the form of this reputable international journal.

The Journal of Trade and Industrial Policies (JTIP) intends, by actively utilizing the capacity of reputable national and international conferences, to enhance the scientific quality and applied depth of articles and to open the path of knowledge flow from global actors to the country's scientific community and vice versa. Furthermore, given the growing role of knowledge-based companies in the technology ecosystem and their position in the idea-to-product value chain, this journal will be a platform for purposeful invitations to development organizations such as IDRO, IMIDRO, the Geological Survey and Mineral Explorations of Iran, specialized associations, production unions, and science and technology parks to expose their experiences, research analyses, and operational results to international judgment and scientific transfer.

The necessity of launching this journal becomes more prominent when we know that Iran, despite possessing massive industrial capacity, rich mineral reserves, and being located on the golden highway of regional trade and enjoying a distinguished geopolitical position, has so far made less use of the capacity of a specialized English-language journal to reflect the scientific and policy achievements of these fields globally. This journal is a direct response to this strategic gap, to be a connection point for explaining Iran's role in regional and global value chains and a framework for constructive dialogue with international knowledge. In a world where responding to complex development issues requires knowledge-based approaches, this initiative has opened a new window to scientific cooperation and welcomes the participation of all researchers in the fields of industry, trade, economics, management, technology, and energy. Accordingly, in its first policy and research step, this journal addresses one of the most vital and decisive regional issues in its inaugural article: the dangerous overlap of "geopolitical conflicts" and the "necessity of redesigning industrial policy" in the Middle East region.

2. Anatomy of the Crisis in the Middle East: Intersection of Supply Shocks and Structural Rigidities

The Middle East region is today at a historical turning point; a point where the economic destiny and human life of millions of people have been subjected to severe geopolitical shocks. What has occurred in recent developments is the unveiling of a composite and multi-layered shock whose destructive effects have cast a shadow through various channels on the body of regional economies, from hydrocarbon-dependent economies in the Persian Gulf to fragile and transitional economies. The central issue for the research community is to go beyond cross-sectional analyses and dissect the complex duality that exists between the necessity of emergency management of conflict-induced shocks and the requirement to achieve sustainable growth through smart industrial policy.

The fundamental distinction of the current conflict from previous crises is its manifestation in the form of a full-scale supply shock; a shock whose main focus is the serious disruption in the vital artery of the Strait of Hormuz. The dramatic jump in oil prices and the ascent of the geopolitical risk index to unprecedented levels in the last two decades are proof of the importance of the Strait of Hormuz and the trans-regional dimensions of this crisis. However, the contagion of this shock to regional economies has not been symmetrical, but is a direct function of the degree of economic exposure, that is, the degree of dependence on oil revenues, and the degree of geographical exposure.

Countries such as Iraq, Kuwait, and Qatar, whose main artery of oil and gas exports is tied to enclosed sea routes, have suffered the most severe economic contraction, so much so that the economic growth outlook of a country like Iraq has fallen from positive figures to heavy contraction. In contrast, countries like Saudi Arabia and the United Arab Emirates, thanks to utilizing land routes and parallel pipelines to alternative ports, as well as possessing a more diversified production structure, have shown relative resilience against the initial shock. This clear divergence proves that the Persian Gulf economy is no longer a unified structure, but constitutes a heterogeneous spectrum of varying degrees of vulnerability and resilience.

3. Channels of Crisis Contagion and the Recreation of Chain Insecurities

The channels of transmission of this crisis have extended beyond energy markets and have targeted the social pillars and production structure of the region. Population displacement in countries such as Lebanon has put additional pressure on public infrastructure, welfare services, and already weak labor markets. At the same time, one of the most dangerous channels of contagion is the threat to food security through the market for chemical fertilizers and agricultural inputs. The transit of a massive volume of global urea exports through the Strait of Hormuz and the increase in the price of natural gas feedstock have led to the formation of cost-push inflation in the agricultural sector. This has severely increased the cost price of food and placed the balance of payments and the national currency value of grain-importing countries under crushing pressure, a situation whose damage will be directly borne by lower-income deciles. Furthermore, the services sector, especially tourism, which has a determining share in the GDP of countries such as the UAE, Jordan, and Lebanon, has faced an obvious pause. Historical experiences show that reconstructing the security image and reviving the flow of tourism in the region will require a long, multi-year interval. In the financial dimension as well, the intensification of geopolitical risk has caused an increase in the yield spread of sovereign bonds and a rise in the credit default swap rate for countries such as Pakistan, Egypt, and Bahrain.

In such a volatile atmosphere, reviewing industrial policy is not merely a technical choice, but a fundamental necessity for laying the foundation of a “Resilient Economy.” Unlike the common state-centered models based on rent in the region, which are often caught in the trap of capital-intensive and low-yield projects, Iran’s approach is focused on “endogenization and exogenization.” In this paradigm, industrial policy acts as a strategic tool for localizing value chains, enhancing technological capabilities, and reducing dependence on import bottlenecks for capital goods. This view does not mean isolation; rather, it is a redefinition of the country’s position in the global chain through strengthening “acquired advantages” instead of relying solely on “natural advantages.” In fact, sustainable resilience against external shocks is the product of the link between knowledge-based policy-making, targeted support for leading industries, and the creation of a flexible production structure that can preserve and multiply economic independence in geopolitical storms. Historical experiences show that reconstructing the security image and reviving the flow of economic prosperity in the region will require a long, multi-year interval.

Thus, industrial policy must confront serious challenges such as the risk of pushing the private sector to the margins, inefficient allocation of resources in high-cost, low-yield projects, and the inability to create sustainable and high-quality employment for native workforces. In contrast, middle-income countries, due to severe financial constraints, do not have the same power of state instrument-making and mostly resort to tariff-based support tools. Peace and sustainable stability are not an idealistic variable, but a rational and undeniable prerequisite for any economic and commercial development. In the absence of geopolitical stability, neither smart industrial policy will come to fruition, nor will private sector investment take shape, nor will supervisory institutions have the possibility to consolidate.

4. Conclusion: Resilient Economy and Structural Resilience in Iran

Ultimately, the current crisis, with all its crushing consequences, can be a point for a fundamental rethinking of the development paradigm of the region and Iran, and an opportunity for transition toward diverse, resilient, knowledge-based, and institution-oriented structures. Iran, backed by nearly half a century of lived experience in the arena of policy-making and facing complex economic shocks and the severest sanctions a country can face, knows well that passing through geopolitical crises is not dependent on passivity, but requires strengthening "structural resilience" through redesigning industrial policies. The "Resilient Economy" strategy in this approach does not act as an isolationist strategy, but as a driving model for enhancing internal capabilities and stabilizing Iran's role-playing in regional value chains. Utilizing rich mineral reserves, extensive infrastructural capacities, and the unparalleled geopolitical position on trade highways are strategic advantages that, when linked with knowledge-based governance, pave the way for passing through this storm. Relying on these solid foundations, Iran will not only successfully pass through this historical transition but, by rearranging its industrial and commercial position, will play a vital role as a reliable anchor in the new economic architecture of the region.

The "Journal of Trade and Industrial Policies (JTIP)" will place scientific, analytical, and empirical achievements to international peer review in this same direction to create a firm link between academic research, policy decision-making, and the realities of the global industry and trade arena.

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Applying the Advocacy Coalition Framework to Analyze Iran's Automotive Industry Strategy

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Abstract

Iran's automotive industry, despite decades of governmental support and its strategic position, has failed to achieve sustainable and competitive development. Based on the author's doctoral dissertation in Public Policy, this study asks why the cycle of failure in automotive policy persists in Public Policy, poses the question of why the cycle of failure in automotive policy persists. Utilizing the Advocacy Coalition Framework (ACF), it analyzes the conflicts among three producer coalitions, centered on the national brand, assembly, and imports, during the period from 1991 to 2024. The research method is based on systematic grounded theory, employing the analysis of documentary and media data. The findings indicate that the lack of a unified and stable strategy stems from a fragile balance among the coalitions and the reproduction of contradictory decisions with each change of government. External shocks, such as sanctions and currency crises, have not led to policy learning; instead, they have pushed policymaking back toward deeply rooted protectionist beliefs. Policy learning has largely been intra-coalition and limited to secondary beliefs, while inter-coalition learning has not occurred due to intense conflict and the devil-shift phenomenon. Consequently, the automotive industry suffers from the accumulation of unfinished policies and unresolved conflicts. Finally, a three-stage transition model, comprising smart assembly, regulated imports, and the revival of a development-oriented national brand , is proposed.

Keywords: Automotive Industry, Advocacy Coalition Framework, Policy Learning

چکیده

صنعت خودروسازی ایران علیرغم دهه‌ها حمایت دولتی و برخورداری از جایگاه راهبردی، در دستیابی به توسعه‌ای پایدار و رقابت‌پذیر ناکام مانده است. این پژوهش، برگرفته از رساله دکتری خط‌مشی‌گذاری عمومی، به تبیین علل پایداری «چرخه شکست سیاست‌گذاری» می‌پردازد. این مطالعه در چارچوب نظریه «ائتلاف‌های حامی» و با اتکا به روش نظریه داده‌بنیاد نظام‌مند بر پایه تحلیل اسنادی و رسانه‌ای، منازعات میان سه ائتلاف اصلی محورهای برند ملی، مونتاژ و واردات را در بازه زمانی 1991 تا 2024 واکاوی کرده است. یافته‌ها حاکی از آن است که فقدان دکترین و استراتژی سیاستی منسجم، ناشی از تعادل شکننده میان ائتلاف‌ها و بازتولید تصمیم‌های متعارض با هر چرخش دولت است. تکانه‌های برون‌زا نظیر تحریم‌ها و بحران‌های ارزی نیز به‌جای تسهیل «یادگیری سیاستی»، سیاست‌گذاری را به رجعت ساختاری به‌سوی باورهای کهن حمایت‌گرایانه سوق داده‌اند. فرآیند یادگیری سیاستی عمدتاً درون‌ائتلافی و محدود به باورهای ثانویه مانده و یادگیری بین‌ائتلافی به‌دلیل قطبی‌شدگی، تعارض منافع و بروز پدیده «شیطنت‌انگاری متقابل» عقیم مانده است؛ وضعیتی که انباشت سیاست‌های ناتمام و منازعات حل‌نشده را رقم زده است. در پایان، الگویی سه‌مرحله‌ای برای گذار پیشنهاد می‌شود که مشتمل بر مونتاژ هوشمند، واردات تنظیم‌شده و قاعده‌مند، و احیای برند ملی با رویکردی توسعه‌گراست.

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Introduction

Despite strategic position and decades of government support, Iran's automotive industry remains one of the most problematic public policy arenas. The sector produced over 1.12 million vehicles in 2024 (14% of industrial output, 2% of GDP) but has failed to achieve sustainable, quality-driven, or globally competitive development. This raises a fundamental question: why, despite extensive investment, import bans, and annual production exceeding one million vehicles, has the industry not progressed toward sustainable development?

This question matters because Iran's auto industry is an arena of political contestation and governance dysfunction. Previous studies have focused on four approaches: (1) lack of coherent industrial policy (Azhdari & Shojaee, 2015; Nadiri et al., 2019; Maadi Roudsari et al., 2019; Fartoukzadeh & Tahmasebi, 2020); (2) rentier political economy and unhealthy firm-government relations (Tavasoli Roknabadi et al., 2025; Soleimani et al., 2023; Beigi et al., 2022); (3) governance failure and uncoordinated regulation (Esmaeilipour Masuleh & Sadeghi Niaraki, 2021; Ameri Shahrabi et al., 2024; Ameri & Samak Jalali, 2024); and (4) weak innovation systems (Arjmandi et al., 2023; Naghizadeh et al., 2018, 2022; Dini Turkamani et al., 2020). Despite their analytical richness, these approaches fail to explain a recurrent pattern: nearly every administration over three decades has adopted rational policies on paper, yet a deep gap persists between policy documents and implementation. The problem lies in structures that block implementation.

Asking "How has the recurrent cycle of policy failure been linked to conflicts among national-brand, assembly, and import coalitions?" and using the Advocacy Coalition Framework (ACF), this study argues that Iran's auto industry is an arena of confrontation among three coalitions: (1) national-brand production (self-sufficiency as security necessity); (2) assembly (foreign collaboration for technology and diversification); and (3) import (liberalization to break monopoly). This perspective illuminates why one coalition prevails, which shocks destabilize the balance, and why policy learning rarely leads to lasting change.

The ACF (Sabatier & Jenkins-Smith) is suited for analyzing high-conflict, complex policies (Jenkins-Smith & Weible, 2025). Through three-tiered belief systems, policy-oriented learning, and external shocks, it explains stability and change in policy subsystems. Using systematic grounded theory (Strauss & Corbin) and analyzing documentary and media data through open, axial, and selective coding, this study identifies the core category of institutional lock-in resulting from absence of a coherent strategy and reproduction of contradictory decisions driven by coalitional conflicts.

Theoretical Framework

The Advocacy Coalition Framework (ACF) is a mid-range theory developed in the late 1980s by Sabatier and Jenkins-Smith. It emerged in response to inadequacies of traditional stage-sequential theories, emphasizing complexity, ambiguity, and the role of beliefs and coalitions. The ACF requires long time horizons (a decade or more) and comprises six main components (Nohrstedt et al., 2023).

First component is Policy Subsystem; the primary unit of analysis. Unlike theories focusing on the state, the ACF focuses on actors from various levels (governmental, private, civil and media) who regularly seek to influence a specific policy domain. Subsystem boundaries are redefined by actors through contestation. Second component is Policy Actors; individuals or organizations seeking to influence the subsystem. They possess bounded rationality and rely on belief systems to simplify the world.

Third component is Three-tiered belief systems – (a) Deep core beliefs: fundamental normative values guiding actors across all policy domains, highly resistant to change; (b) Policy core beliefs: subsystem-specific normative and empirical beliefs (diagnosis of problems, value prioritization), transformable through external shocks or major policy failures; (c) Secondary beliefs: specific policy instruments (tariffs, incentives, regulations), most flexible and amenable to change.

Fourth component is Advocacy Coalition – actors from different institutions sharing common policy core beliefs, coordinating activities to translate beliefs into policy or prevent change. Public policies reflect the balance of power among competing coalitions. Fifth component is Policy-oriented learning – enduring changes in thought or behavior from experience, leading to belief revision. Learning occurs primarily at secondary belief level under moderate conflict; cross-coalition learning increases with policy forums facilitating dialogue.

Sixth component is Policy change in four pathways: (1) external events (socio-economic transformations, crises); (2) internal events (policy failures, corruption exposure); (3) policy-oriented learning (gradual instrument changes); (4) negotiated agreements under "hurting stalemate."

This study employs the ACF to explain fluctuations in Iran's automotive policymaking over three decades, specifically how conflicts among national-brand, assembly, and import coalitions, along with external shocks (sanctions, currency crises), explain lock-in and contradictory policy reproduction. Using Strauss and Corbin's systematic grounded theory, data from official documents (laws, parliamentary reports) and media archives (Hamshahri and Donya-e-Eqtesad) were analyzed through open, axial, and selective coding, yielding the core category of institutional lock-in from absence of coherent strategy and reproduction of contradictory decisions driven by coalitional conflicts. Triangulation and peer review enhanced trustworthiness.

The National-Brand Production Strategy in Iran

Despite fluctuations, the national-brand production strategy has been the hegemonic narrative in Iran's automotive policy conflicts for three decades. Emphasizing domestic design, development, and Iranian intellectual property, it was accompanied by developmental logic and institutional cohesion in certain periods but mostly devolved into symbolic, protectionist discourse without technological foundation.

The strategy revived in the 1990s post-Iran–Iraq War. The industry, suspended in the 1980s with annual production of only 24,000 vehicles, became associated with two ideas during Reconstruction: economic self-sufficiency (a Revolutionary pillar) and authoritative development (enhancing Iran's power as a model for Muslim nations). The 1993 currency crisis served as an external shock enabling national-brand coalition dominance. The administration imposed a complete import ban and enacted the 1992 Automotive Law, placing heavy tariffs on CBU imports while offering six-year tax exemptions to domestic manufacturers, effectively granting Iran Khodro and Saipa control of the entire market (Moudoudi, 2005; Manteghi, 2011).

Under Khatami's first administration, the coalition reached peak cohesion and legitimacy. Support for domestic production included a clear developmental horizon: 500,000 units, 30% exports, powertrain localization, and forex equilibrium. Foreign investment was accepted only if it led to exports, viewed as a tool to strengthen the national brand. Policy instruments rested on three pillars: volume increase, local content deepening, and import bans. Rapid production growth, parts manufacturer expansion (from dozens to hundreds), and the Samand as the first national car reinforced belief in success. However, seeds of future contradictions were sown: exclusive focus on quantity over quality, and technological dependence on Peugeot, design knowledge remained French.

During Khatami's second administration, the coalition faced a contradiction. Policymakers recognized domestic market limits and product inability to compete. An attempt at conditional globalization began (Renault's L90 project) but remained incomplete. A segment of the Majlis and sovereign institutions saw foreign collaboration as "ceding the national market to foreigners," and manufacturers showed little R&D inclination. The coalition remained dominant but lost cohesion, entering hesitation and inaction.

Under Ahmadinejad, the strategy was redefined in ideological, justice-oriented language. Slogans like "national motor," "national car," and "Iran as automotive hub of the Islamic world" emerged, but discourse relied on political mobilization and symbolic self-sufficiency rather than realistic planning. The German-partnered gas-fueled powertrain project failed due to technological gap neglect. Pressure for low-cost cars and import combat pushed manufacturers toward obsolete models. The automobile became a political commodity; price increases tied to public discontent. Policymakers managed consequences rather than reforming cost structures.

During Ahmadinejad's second term, sanctions challenged the coalition, which positioned itself as the only option. Peugeot and Renault withdrew, severely hitting supply chains but enabling return to self-sufficiency discourse. The industry entered survival mode: production fell from 1.5 million to below half, with unprecedented losses. Nevertheless, the coalition leveraged employment (nearly one million jobs) as a social shield to defend its monopoly, reframing criticism as attacks on workers' livelihoods.

Under Rouhani's first administration (JCPOA period), the national-brand coalition was pushed to the margins, replaced by assembly and foreign cooperation. But the 2018 sanctions shock returned the coalition to the center, not from a developmental position, but from survival and crisis management. The 2021 Automotive Industry Regulation Law, despite mentioning conditional imports and technology transfer, became a regressive document due to institutional vetoes and insistence on domestic protection.

Under Raisi and thereafter, the strategy reached institutional lock-in. With coalition consolidation in high-level institutions (centered on the Expediency Discernment Council), imports remained effectively banned. So-called "national" products (Tara, Shahin, Rira), despite claims of domestic design, failed to differentiate from previous models. Limited production and persistent quality issues left them unable to replace obsolete vehicles.

After three decades of unfulfilled promises, public opinion is deeply skeptical of the national brand. Successful experiences (e.g., South Korea) show that building a national brand requires: indigenous technological capability, risk-taking industrial entrepreneurs, market ownership focus, appropriate export timing, design quality, policy persistence, and complementary institutional instruments (Jacobs, 2022). In Iran, these pillars have been absent or, amid coalitional conflicts and external shocks, have failed to materialize.

The Assembly Strategy in Iran

Unlike the dominant national-brand discourse, the assembly strategy in Iran has always played a complementary, marginal role, at times serving as a tool to moderate market pressures. This strategy focuses on producing vehicles designed and owned by foreign manufacturers, with Iran limited to importing CKD kits and assembling them. Despite repeated promises of localization and technology transfer, it has failed to become sustainable. Thailand's smart assembly model, with phased localization, champion models, and export orientation, created a powerful domestic parts chain and global market presence without a national brand (Doner et al., 2021). Iran's path reflects a deep gap from this model.

The assembly coalition emerged in the early 1990s. In 1994, a cabinet resolution approved Kerman Motor's partnership with South Korea's Daewoo (66% Daewoo, 34% Iranian). It stipulated 70% local content by the fifth year and production of Daewoo's latest models. Policymakers defined assembly as a stepping stone toward a national brand, but promises were never realized. Assembly remained confined to low-value-added parts (batteries, tires, decorative components).

During the 2000s, the coalition faced two distinct trajectories. First, state-owned manufacturers (Iran Khodro, Saipa) entered luxury vehicle assembly to offset losses from administered pricing and meet affluent demand: Suzuki Grand Vitara, Peugeot 407, Citroлn C5, Nissan Murano. Projects followed a roadmap (CBU imports then assembly then localization) but stalled at the second stage and ceased with sanctions. Second, private assemblers faced absent incentives for localization. The tiered tariff policy lost efficacy due to weak monitoring and tariff circumvention through cheaper part imports.

A turning point was cooperation with Chery (China) in the late 2000s. Iran Khodro CEO Manteghi defined the S21 project with a cost target of approximately $5,000 per car. Unlike the Renault L90 contract, technology transfer, platform ownership, and global value chain participation were not priorities. The bitter L90 experience, political opposition and repeated amendments, loomed over the project. It was explicitly stated: “If the domestic parts manufacturer cannot produce a part, we will import it from China.” Local content was valued only insofar as it did not hinder low-cost production.

During the 2010s (JCPOA period), the assembly coalition became dominant for the first time. Post-JCPOA agreements with Peugeot and Renault included joint ventures, minimum 40% local content, and 30% exports, a belated attempt to learn from past failures. However, implementation faced delays and institutional incoordination. Localization and export conditions were not met. The Peugeot 2008 started with minimal local content, and costs rose so high that promises of an affordable car became invalid. Experts noted that without 150,000–200,000 units annually, deep localization is not economically viable; policy requirements became symbolic.

The 2018 sanctions shock collapsed the assembly coalition. Peugeot and Renault withdrew, the international financial network was disrupted, and exchange rate jumps shattered supply chains. Private manufacturers (more dependent on imports) faced deeper crisis than state-owned ones; part of their capacity was idled. From Raisi’s administration onward, “Chinese assembly” emerged. With intensified sanctions and blocked competitive imports, major private manufacturers (Modiran Khodro, Kerman Motor, Bahman Motor), exempt from administered pricing, filled the gap left by European, Japanese, and Korean brands. Their share of national production exceeded 24% in 2024. However, unlike Thailand, growth was not accompanied by increased local content depth.

A Parliament Research Center report (October 2025) showed that existing tariff structures allow assemblers with very limited investment and local content of only about 20% (welding, final assembly, painting, simple parts) to circumvent import restrictions (Bakhshi et al., 2025). The tiered tariff policy has been nullified because it monitors where parts were purchased, not where they were actually produced. Several factors have prevented assembly from becoming a successful alternative: absence of phased localization with enforcement; weak logistics infrastructure (contrary to Thailand’s investment in Laem Chabang Port and Eastern Economic Corridor); sanctions impact on supply chains; and assemblers’ short-term interests overriding developmental imperatives.

Thailand raised local parts to over 80% and exported over 60% of production through local content requirements (25% in 1971 to 54% in 1987), champion models (pickups then economic cars), and tax policies linked to industrial objectives (Warr & Kohpaiboon, 2019). In contrast, Iran's assembly has neither generated exports nor avoided high forex intensity. Five private assemblers received over 3.3 billion in foreign currency in 2023, averageing over 13,000 per vehicle. Assembly has become a dependent, forex-consuming model with no significant value added or technology transfer.

The Import Strategy in Iran

Unlike the other two strategies, the import strategy has never become dominant or stable. It has consistently occupied a marginal, defensive position marked by extreme fluctuations. In Iran, imports have not functioned as a permanent strategy (e.g., UAE or Qatar) nor as a tool for market regulation and competitive pressure (e.g., South Korea, EU). Rather, they have been framed as a political lever and source of luxury vehicles for affluent classes during forex abundance, and as an "original sin", capital flight and foreign dependence, during crises.

Imports have consistently been accompanied by taboo. In the 1980s, imports ceased and production fell to ~24,000 vehicles. In the early 1990s, responding to the 1993 currency crisis, the 1992 Automotive Law imposed heavy progressive tariffs (exceeding 100%) plus six-year exemptions for domestic producers, making CBU imports economically unviable. This law entrenched a pattern: whenever the country faces forex shortage or political crisis, vehicle imports are first sacrificed. During the 1990s, import share approached zero; state-owned manufacturers operated in a hothouse environment mass-producing Paykan then Peugeot 405.

In the 2000s, with oil revenue abundance, the first relative opening emerged. In 2005, following partial tariff reductions, imports resumed and grew to a peak of ~102,000 units by 2014. However, import share never exceeded 10%, and imports remained limited to luxury models for the wealthy. This had two consequences: (1) imports did not create competitive pressure (negligible share, high prices posed no threat); (2) the public image of imports as "luxury goods for the upper classes" strengthened anti-import discourse. Any liberalization attempt was met with accusations of "serving wealthy interests and causing capital flight."

During Khatami's second administration, "imports as competitive pressure" entered official discourse for the first time. Economists, parliament members, and Commerce Ministry experts identified market monopoly as the cause of low quality and high prices. A seven-year tariff reduction plan was formulated. However, this coalition remained a minority against the dominant narrative ("risk of destroying nascent industry" and "capital flight") and could not change policy. The market remained closed; imports became a potential threat rather than an operational tool.

During Ahmadinejad's first administration, anti-import discourse intensified ideologically. Luxury imports were attacked as "promoting un-Revolutionary culture" and "extravagance." The Supreme Leader also cautioned against the phenomenon. The import tariff was fixed at

90% for most of this period, and imports entered at astronomical prices. Paradoxically, state-owned manufacturers themselves entered luxury vehicle assembly (Peugeot 407, Citroлn C5, Nissan Murano), reproducing the same social and class effects of imports without any competitive benefits.

The 2010s can be regarded as the period when imports were sacrificed to external shocks. During Rouhani's first administration (JCPOA), imports flourished briefly with greater variety. But the 2018 sanctions shock and unprecedented exchange rate jump led to a complete import ban. Preserving forex for essential goods prevailed over other considerations. The ban continued until 2022. In the interim, the market became extremely monopolistic, the factory-market price gap reached unprecedented dimensions, and the automobile became a capital good and speculation tool.

The November 2021 Automotive Industry Regulation Law could have been a turning point. It permitted imports but imposed four conditions: (1) technical specifications prioritizing electric/low-consumption vehicles; (2) after-sales service and technology transfer; (3) importer technical qualifications and official dealership representation; (4) import ceiling based on market regulation and forex resources. Implementation faced serious obstacles. First, in 2024, the High Council for Oversight (under the Expediency Discernment Council) rejected parliament's resolution to reduce tariffs and increase forex allocation, instead ruling for 100% import tariffs. This demonstrated that the anti-import coalition is entrenched in high-level institutions. Second, official dealership representation was practically impossible under sanctions, blocking large-scale imports.

In 2023–2024, subsequent amendments eased used and electric vehicle imports. Article 11 permitted used vehicle imports without technology transfer or dealership conditions. Under January 2024 implementing regulations, electric vehicle import tariffs were reduced to 4%, unprecedented in Iranian tariff history. Nevertheless, total import value in 2024 reached $1.31 billion (over 50,000 units), still considerably below the 2014 peak of 102,000 units.

In sum, imports in Iran are caught in the duality of conditional opening during forex abundance and complete prohibition during crises. This extreme fluctuation has three consequences. First, domestic manufacturers have never experienced sustained competitive pressure, lacking incentive to improve quality or reduce costs. Second, consumers have been deprived of choice: during prohibitions, forced to buy low-quality, expensive domestic vehicles; during limited openings, only the affluent can afford high-tariff imports. Third, policymakers have never used imports as an intelligent signaling tool to domestic production and assembly coalitions. While Australia's experience shows that gradual but unplanned tariff removal can cause industry collapse, Iran's experience reflects a different failure: preserving domestic monopoly through periodic import bans without protection leading to quality or competitiveness. The policymaker protects the industry and accepts heavy social and economic costs, yet fails to develop it. The policymaker prohibits imports but creates no competitive alternative.

Advocacy Coalitions within the Three Strategies

The research findings are organized through core ACF concepts to demonstrate how coalitional conflicts, belief systems, external shocks, and policy-oriented learning have shaped Iran's automotive policy subsystem over three decades.

The automotive policy subsystem consists of a complex network of actors seeking to influence policies: Ministry of Industry, Mine and Trade; IDRO; Majlis; Expediency Discernment Council; Competition Council; National Standards Organization; Environmental Protection Organization; Central Bank; Iran Khodro and Saipa; private manufacturers; parts makers; importers; labor unions; and media. Subsystem boundaries are not fixed. Actors such as the Fuel and Transportation Management Headquarters (Ahmadinejad) or Vice Presidency for Science and Technology (Raisi) have entered at various times. Adjacent subsystems, foreign policy (sanctions, JCPOA), energy policy (gasoline rationing, subsidies), and social policy (job creation, youth population), continuously overshadow automotive policies and redefine boundaries.

Analysis reveals three coalitions with distinct three-tiered belief systems.

Deep core beliefs: The national-brand coalition holds that development requires a strong national industry and industrial independence is part of national security, beliefs reinforced, not weakened, by sanctions or currency shocks. The assembly coalition prefers gradual industrial development based on learning and integration into global value chains, viewing the state as facilitator rather than operator. The import coalition believes consumer welfare and competition take precedence over self-sufficiency; the state should not protect inefficient industries lacking comparative advantage.

Policy core beliefs: The national-brand coalition prioritizes preserving large domestic manufacturers and maximum localization, even at quality cost. The assembly coalition emphasizes partnership with foreign manufacturers and technology transfer through assembly, advocating moderate tiered tariffs. The import coalition regards import liberalization and tariff reduction/elimination as its policy core, focusing policymakers on safety, standards, and environment.

Secondary beliefs: Disagreements center on tariff rates, import quotas, localization requirements, pricing conditions, and tax exemptions. The national-brand coalition leveraged local content requirements to dominate the policy arena, keeping private assemblers below 5% of the market for over two decades, prevented import growth via heavy tariffs, and used forex allocation controls. The assembly coalition advocates tax incentives, low tariffs, and forex allocation for parts imports, justifying activities through regional planning policies (assembly lines in western and southern provinces). The import coalition's maneuvering focused on breaking the import monopoly, resulting in a grey market for imports from the 2010s onward. Tariff reduction succeeded in the EV sub-sector during the fourteenth administration (2024–present). Proposals for used vehicle imports and imports for Iranians abroad remain largely theoretical. Table 1 summarizes the three-tiered belief systems.

The ACF states that external shocks can disrupt coalition balance and create conditions for policy change. Three major shocks fundamentally altered Iran's coalition balance: First, the 1993 currency crisis led to a complete import ban and national-brand coalition dominance. Preserving forex reserves prevailed over all other considerations; the import coalition was eliminated from the policy arena. Second, the 2018 sanctions reimposition and currency jump returned the national-brand coalition to the center, not from a developmental position but from survival and crisis management. The assembly coalition (dominant during Rouhani's first administration) quickly collapsed; foreign partners left Iran. Third (an internal event), the Supreme Leader's direct intervention in the automotive debate and dissatisfaction with domestic product quality led to the Automotive Quality Improvement Law (2010), strengthening regulation and standards for a period.

In Iran, policy learning has been largely intra-coalitional and limited to secondary beliefs. Example: foreign contracts. Khatami's second administration, after a decade of self-sufficiency efforts culminating in the Samand, attempted foreign cooperation within the national-brand framework via the Renault L90 project but failed. Rouhani's first administration learned from this and incorporated 40% localization, 30% exports, and FDI into post-JCPOA agreements with Peugeot and Renault. However, this learning did not penetrate policy core beliefs. With the 2018 sanctions shock, policy reverted to deeper beliefs.

Cross-coalition learning (belief change through interaction with rivals) is extremely rare. Dialogues between the Ministry of Industry, Mine and Trade and import critics typically lead not to mutual persuasion but to a "devil shift" (exaggerating opponents' power and malice). Opponents of imports accuse proponents of being "agents of affluent class interests and profiteers"; proponents accuse opponents of "supporters of monopoly and low-quality production."

The research findings indicate four distinct periods of coalition balance over three decades:

1. 1990s (Khatami's first administration): The national-brand coalition achieved complete hegemony with developmental logic (production, localization, export horizon). The assembly coalition played a complementary, marginal role. The import coalition was effectively eliminated from the policy arena.
2. 2000s (Khatami's second administration through Ahmadinejad): The national-brand coalition remained dominant but lost internal cohesion. The assembly coalition was fragile, exposed to accusations of "ceding the market to foreigners." The import coalition appeared only discursively and very weakly.
3. 2010s (Rouhani's first administration): The assembly coalition and conditional foreign cooperation became dominant for the first time. The national-brand coalition was pushed to the margins but not eliminated. The import coalition achieved analytical legitimacy. However, the 2018 sanctions shock disrupted this balance, and the national-brand coalition (with survival logic) became dominant again.

4. 2020s (Raisi and thereafter): “Institutional lock-in” prevails. The national-brand coalition is not only dominant but entrenched in high-level institutions (Expediency Discernment Council). The import coalition is removed from the policy agenda. The assembly coalition is reduced to a passive form dependent on Chinese automakers. Unlike previous periods, effective policy forums for cross-coalition dialogue are absent; even parliamentary laws (e.g., reducing import tariffs) are vetoed by high-level institutions.

The ACF predicts cross-coalition learning is more likely under moderate conflict. In Iran, conflict among coalitions has often been intense. Actors view each other as enemies, not rivals; moral and political accusations replace technical dialogue. Policy-oriented learning has been largely intra-coalitional and limited to secondary beliefs.

Example: the low-cost car experience. During Khatami’s administration and then under Ahmadinejad, the promise of a car priced under $10,000 was made but failed due to lack of clear price definitions, standards, and economic models. Under Raisi, this promise was repeated as the “economic car,” yet still lacked clear operational definition and appropriate production/supply strategies. This demonstrates that even intra-coalitional learning at the secondary belief level has been incomplete; policymakers have not learned from their own past failures.

Conclusion and Policy Recommendations

This study was formed in pursuit of answering the fundamental question of why Iran’s automotive industry, despite decades of government support, extensive investment, and annual production of over one million vehicles, has failed to achieve sustainable, quality-driven, and globally competitive development. The research findings demonstrated that the answer to this question cannot be sought solely in the absence of industrial policy, rentier political economy, regulatory failure, or weak innovation systems. Rather, the factor that has had the greatest influence is the specific pattern of coalitional conflict within the automotive policy subsystem. In the midst of the confrontation among the three strategies, national-brand production, assembly, and imports, policymakers are unable to establish a single, consistent strategy over the long term. Each time a coalition comes to power, it ignores or dismantles the infrastructure of the previous coalition, and the cycle begins anew. Iran’s automotive industry suffers not from a lack of policies, but from the accumulation of unfinished policies and unresolved coalitional conflicts. The drafting of macro-policy documents at the beginning of each administration cannot provide a solution to this problem. With each change of government, instead of the continuation of policy learning, there has been a return to deep protectionist beliefs. In this situation, the struggle among coalitions has itself become the problem, rather than a means of solving it.

Based on the findings of this study, any redesign of Iran's automotive policy strategy first requires accepting the reality that abrupt change and the eradication of the dominant coalition are not possible. Three decades of experience have shown that such an approach only leads to the reproduction of previous cycles. Instead, a three-stage transition model with a defined time horizon and objective performance indicators is proposed.

Stage One: Adoption of a Smart Assembly Approach for a minimum of five years. In this stage, the policymaker must formally accept the assembly strategy as the dominant strategy. However, this must not be the current type of assembly, which consists of importing CKD kits with localization below 20% and no technology transfer, but rather a smart assembly approach inspired by successful experiences such as those of Thailand, Turkey, and Brazil.

Stage Two: Regulated Imports covering the second five-year period of the plan. After the parts manufacturing industry has been strengthened in the first stage and the increase in local content has been institutionalized within automotive firms, imports are opened in a controlled manner. The purpose of imports at this stage is to create competitive pressure on domestic manufacturers and to close the price and quality gap. The policymaker does not aim to meet the entire market demand through imports.

Stage Three: Revival of a Developmental National Brand – the final stage of the proposed plan. The implementation timeframe for this strategy is long-term, covering years eleven through twenty of the program. The essential consideration at this stage is to avoid creating a national brand in a hothouse environment protected from the rules of competition.

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Diversion Of Money into Unproductive Activities in Iran's Economy

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Abstract

This paper examines how the use of money in Iran's financial systems has diverted from productive to unproductive activities. Over the last three decades, with the exception of a few years, the liquidity growth rate in the Iranian economy has been greater than the sum of inflation rate and real GDP growth. This difference, according to the quantity theory of money, can be interpreted as a reduction in the income velocity of money. However, considering that the inflation and interest rates have been continuously high (in some cases above %20), it may not be reasonable to accept that the circulation of money has been getting slower than before. One explanation of this paradox is that, during the aforementioned period, the circulation of money did not decline, but "instead the ratio of irrelevant -to -GDP transactions to total transactions (relevant and irrelevant) has gone up". The increase in this ratio would be largely attributed to a disproportional expansion of unproductive activities in operating within Iran's economy. Our hypothesis is that the significant increase in the liquidity growth rate, has been a drag on economic productivity and growth, instead of facilitating and enhancing economic growth. To test this hypothesis, we considered the difference between the liquidity growth rate and the sum of inflation rate and real GDP growth as a proxy of the unproductive activities and then estimated its impact on the GDP. The results indicate that increases in unproductive activities have had a significant negative impact on the GDP. This finding supports our hypothesis that the high growth rate of liquidity in Iran's economy has been in favor of the unproductive activities and thus, a drag on the economic growth.

Keywords: Unproductive Activities, Transaction Velocity of Money, Iran Economy

چکیده

این مقاله به واکاوی انحراف منابع پولی در نظام مالی ایران از فعالیت‌های مولد به‌سوی فعالیت‌های غیرمولد طی دوره ۱۹۹۸ تا ۲۰۲۴ می‌پردازد. طی سه دهه اخیر، نرخ رشد نقدینگی در اقتصاد ایران پیوسته از مجموع نرخ تورم و رشد تولید ناخالص داخلی حقیقی فراتر رفته است؛ شکافی که در چارچوب نظریه مقداری پول، به‌منزله کاهش سرعت گردش درآمدی پول تعبیر می‌شود. با این حال، با توجه به استمرار نرخ‌های تورم و سود بانکی بالا، پذیرش فرضیه کندتر شدن چرخش پول با منطق اقتصادی ناسازگار است. تبیین این پارادوکس نشان می‌دهد که سرعت گردش پول کاهش نیافته، بلکه نسبت مبادلات نامرتبط با تولید ناخالص داخلی به کل تراکنش‌ها افزایش یافته است؛ رخدادی که ریشه در انبساط نامتوازن بخش‌های سفته‌بازانه و نامولد دارد. فرضیه پژوهش این است که رشد شتابان نقدینگی، به‌جای تسهیل رشد اقتصادی، به مانعی در مسیر بهره‌وری بدل شده است. برای آزمون این فرضیه، مازاد رشد نقدینگی نسبت به مجموع تورم و رشد تولید ناخالص داخلی حقیقی به‌عنوان متغیر جانشین (پراکسی) فعالیت‌های غیرمولد در نظر گرفته شد. نتایج تجربی بیانگر اثر منفی معنادار گسترش فعالیت‌های غیرمولد بر رشد اقتصادی است. این یافته تایید می‌کند که هدایت نامناسب نقدینگی، با تغذیه بخش‌های غیرمولد، همچون ترمزی در برابر توسعه صنعتی و رشد اقتصاد ملی عمل کرده است.

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1. Introduction

In this section, at first, the literature pertaining to the unproductive activities and their characteristics is reviewed along with the author's point of view about such activities. Based on some experts' points of view, we, then, explain why the resources and talents tend to support the unproductive sector.

1-1. What are unproductive activities?

Bhagwati (1982) has called phenomena such as lobbying for protection, competing for a share of industrial or import licenses, inducing legislatures to enact monopolistic barriers to domestic entry, utilizing resources to evade "price" or "command" governmental regulations as directly unproductive profit-seeking activities. From his point of view, the essential characteristic of these activities is that these activities do earn income and make profit but don't produce goods and services that enter the utility function directly (by increased production) or indirectly via increased availability to the economy of goods that increase the utility of the individuals. Additionally, since these unproductive activities use real resources, their effect is to contract the available set of consumption possibilities of the economy as a whole. Baumol (1990) was more concerned about the form of allocation of entrepreneurial talent among the productive and unproductive activities than about the impact of unproductive activities on supply quantity. Baumol (1990) emphasized that at any time and place, this is the form of allocation of entrepreneurial talents across the productive and unproductive activities that mainly determines the magnitude of the benefit that the economy derives from its entrepreneurial talents as some exercises of entrepreneurship could sometimes be unproductive or even destructive. Baumol also pointed out that the allocation of entrepreneurship between the productive and unproductive activities can have a profound effect on the innovativeness of the economy and the degree of dissemination of its technological discoveries. Christopher et al. (2010) highlights the fact that unproductive activities are the cause of underdevelopment, poverty and low growth. The authors stated that in an institutional context, underdevelopment is not due to a lack of inputs, but rather to a lack of incentive for productive activities. They also believe poverty traps are due to an institutional environment that discourages productive activities while typically rewarding non-productive actives, not to a lack of inputs. Naude (2008) also has a similar opinion that all entrepreneurs won't be engaged in the activities that have positive consequences for the economic growth (productive activities). While all entrepreneurs are motivated to seek opportunities for self-advancement, in some cases the private benefits of their actions will be outweighed by the social costs. He also believes that perverse allocation of entrepreneurial ability to rent-seeking, evasion, and predatory activities along with low quality entrepreneurial ability can contribute to the economic stagnation and even a 'development trap'. Henrekson (2007), emphasizing on the quality of entrepreneurial activities, has questioned a premise underlying many studies (usually implicitly) that more entrepreneurship is always better. Henrekson (2007), suggests that this is not necessarily true, because there is no guarantee that a potential entrepreneur will actually put his or her time and effort into the productive activities. He has also pointed out that “If the institutional setting encourages behavior that is wasteful or destructive from the point of view of society, more entrepreneurship means less prosperity.” Henrekson’s also claimed Baumol’s idea is also applicable for rich and developing countries as there are many instances of unproductive or predatory entrepreneurship in rich countries as well, although wealthy word does generally a good job of using the entrepreneurial talents for inherently productive purposes and this is what actually explains a large part of their wealth.[1]

“In this paper, we define unproductive activities as activities that fail to create any real economic value, earn very high incomes, are a drag on the productivity and growth through the absorption of limited resources as well as the increased rate of returns and the discount rates which consequently raise the opportunity costs for productive investments”. Examples of unproductive activities are corruption, rent seeking, smuggling, illegal and even unnecessary legal activities that receive a remarkable fraction of total national income and actually restrict the productive activities to a small proportion of total income. Based on these criteria, if some conventional productive activities deviate from their functions, they could be considered as unproductive activities. If the financial activities, for instance, are a drag on the growth instead of facilitating, these would be placed into the unproductive category, though their original function was to facilitate the productive affaires and play a vital role in production process. In brief, some of the following characteristics can be used to define unproductive activities:

1. Failing to create any real economic value, directly or indirectly.
2. Receiving a relatively high income at the expense of about equivalent reduction in income of productive agents. Thus, they change the distribution of income against the productive agents and their expansion moves the economy from being a positive-sum-game to a zero-sum-game.
3. Increasing the opportunity costs for the productive investments through their own high returns and increasing the discount rates for the evaluation of investment projects.
4. Eliminating them from the economy not only doesn’t harm the long run economic growth and development but also facilitates it.
5. limit or hamper the competitive production of goods and services directly or indirectly.

1. Adam Smith (1776) divided the labor force into productive and unproductive: “There is one sort of labor that adds to the value of the subject upon which it is bestowed; there is another which has no such effect. The former as it produces value, maybe called productive, the latter unproductive labor.” But this idea is somewhat different from those we quoted above.

1-2. Why do resources and talents tend to move toward the nonproductive activities?

The economy as a whole can be considered a one social game and, thus, its rule and payoffs matrixes determine how resources and talents are allocated across activities. Christopher et al. (2010) believes that while inputs and resources are clearly necessary for economic growth, these things alone can't contribute effectively to economic growth - unless formal and informal institutional structures are conducive to productive activities. If those institutions attach a relatively high payoff to non-productive activities, the outcome will be persistent stagnation and underdevelopment regardless of the level of inputs. Therefore, Christopher et al. (2010) points out:

> *"where inputs are not being transformed into outputs, it is because the payoff associated with the process of transformation is not sufficient to induce productive entrepreneurs to undertake production.".*

Baumol (1990) introduced the relative reward as the main determinant of unproductive activities growth:

> *"at least one of the prime determinants of entrepreneurial behavior at any particular time and place is the prevailing rules of the game that govern the payoff of one entrepreneurial activity relative to another." – again format full quote as a separate paragraph, slightly indented.*

This means that if the rules and payoffs impede earning of an income through activity A, but facilitate earning of an income via activity B, other things being equal, entrepreneurial talents will tend to move toward activity B. If activity B contributes less to growth or welfare than activity A, the consequence of the imposed rules and payoffs will be a drag on economic growth. Baumol (1990) concludes that the rules of the game and payoffs matrix to different entrepreneurial activities play a key role in allocating entrepreneurship across productive or unproductive directions and that this can significantly affect the economy's productivity growth. Hobsbawn (1969) has also supports this idea: "It is often assumed that an economy of private enterprise has an automatic bias towards innovation, but this is not so. It has a bias only towards profit." Henrekson (2006) has quoted North on the role of incentive structure in economic growth and has confirmed that: Douglass North (e.g., 1990) criticized the traditional view that economic growth is achieved by the accumulation of factors of production, while he believes these are just proximate causes of growth but the ultimate causes for development are instead the incentive structure that encouraged individual effort and investment in physical and human capital and in new technology. From Baumol's point of view, incentive structure is in turn determined by "the rules of the game in society" or the institutional setup broadly construed.

Based on the provided discussions, we conclude that the relative returns determine how resources and talents are allocated across activities.

2. The quantity theory of money and some of its experimental hidden angles

Here, the goal is not to contribute to controversial debates on monetary theory but instead we discuss some empirical aspects of the quantity theory of money to explain some strange and paradoxical facts in Iran's economy.

2-1. Some seemingly paradoxical facts

Based on the formula for the quantity theory of money, the historical data shows that in some cases, the income velocity of liquidity has been declining while actually it has been constant:

2-1-1. Diversion of money toward unproductive activities

In recent years, it has been observed that the liquidity growth has been greater than the nominal GDP growth in Iran's economy. According to the quantity theory of money, this implies that there must be a decrease in the income velocity of liquidity. However, according to a basic macroeconomic theory, money doesn't get cold or hot unless inflation expectations, interest rates and the degree of uncertainty all experience sharp (or at least considerable) fluctuations. In other words, money gets cold only when the interest rate and inflation expectations are decreasing[1]. Considering that Iran's economy has continuously experienced a double-digit inflation rate and very high interest rates over recent decades, it would not be reasonable to accept that the circulation of money has gotten slower than before (see Table1).

Table 1 – Inflation and interest rates (percentage)[2]

Year	2001	2002	2003	2004	2005	2006	2007
Inflation rate	11.27	14.33	16.47	14.76	13.43	10.02	17.34
Interest rate	18	18	18	17	18	16	14
Year	2008	2009	2010	2011	2012	2013	2014
Inflation rate	25.41	13.55	10.09	26.29	27.26	36.60	16.61
Interest rate	14	14	16	18	18	24	30
Year	2015	2016	2017	2018	2019	2020	2021
Inflation rate	12.48	7.25	8.04	18.01	39.91	30.59	43.39
Interest rate	28	24	24	25	25	22	22

Source: Inflation rate data from database: World Development Indicators, Last Updated: 12/22/2022

1. See Milton Friedman "The Quantity Theory of Money: a Restatement," in Studies in Quantity Theory of Money, University of Chicago Press 1956.

2. Actual interest rates have been greater than the numbers that are shown in the table.

This situation might be viewed as a paradox or it could mistakenly be concluded, that the quantity theory of money doesn't work for Iran's economy. The quantity equation of money can be broken down though into two different aspects: an accounting aspect (as an identity) and a theoretical aspect. As an identity, the quantity equation of money anywhere and anytime is hold but, in some cases, it needs to be modified or interpreted based on its theoretical aspect. In the evolution path of quantity theory, when we move from the money equation of total transactions (P.T=M.V) to relevant -to- GDP transaction (P.y=M.V), the implicit assumption is that the ratio of relevant -to -GDP transactions , (P.y), to total transactions, (P.T), is constant . If this ratio is constant, income velocity of money (which serves as a residual in the latter equation) would reflect the actual changes in circulation of money. However, if this ratio isn't constant, V in the equation can change without reflecting any actual change in circulation of money. For example, assume the available stock of money in time t1 is 1000 units and the value of total transactions and relevant -to- GDP transaction is 4000 and 2000 units respectively. Thus, the transaction velocity and income velocity of money in time t1 are 4 and 2 respectively. Then assume in time t2 the stock of money is 1100 units and the values of total transactions and relevant-to-GDP transactions are 4400 and 2100 units respectively. According to the quantity equation of money, the transaction velocity and the income velocity of money in time t2 are 4 and about 1.9 respectively. This equation shows that from t1 to t2 the income velocity of money has declined, but actually it hasn't; because 50 units of increased money (of 100 units) have covered 100 units of relevant -to-GDP transactions and 100 units of irrelevant -to-GDP transactions and the other 50 units have covered exclusively 200 units of irrelevant- to -GDP transactions. In other words, the total 100 units of new money have covered 400 units of total transactions and only 50 units of it have covered 100 units of relevant- to-GDP transactions. This example illustrates that although the ratio of relevant-to-GDP transactions to total transactions has declined from1/2 to 21/44 and also the quantity equation of money implies a reduction in the income velocity, both the income and transaction velocities have remained constant (2 and 4 respectively).

2-1-2. Structural changes

Structural changes could also reflect a reduction in the income velocity of money (based on the quantity theory) despite the actual velocity is constant. For instance, in 1960s, the income velocity, calculated using the quantity equation (see Table 2), was very high. In this case, this was not a sign of hot money, but was mostly due to the prevalence of barter transactions.

Table 2- Income velocity of liquidity in Iran's economy in 1960s

1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976
5.78	5	4.36	4.2	4.18	3.94	3.66	3.42	3.27	3.18	3.17	3.03	3.31	3.66	2.9	2.7

Source: Author's calculations using data from the central bank of Iran

Since the late 1960's the Iranian business environment has improved and the economy has become more modernized, resulting in the ratio of barter transactions to total transactions to decreased to almost zero. Hence, according to the quantity equation, income velocity of money as a residual item has declined while in the real world it has actually been constant because the inflation expectations and interest rates haven't been less than before (see Table 3).

Table 3- Changes in Inflation and interest rates in Iran from 1962 to 1977

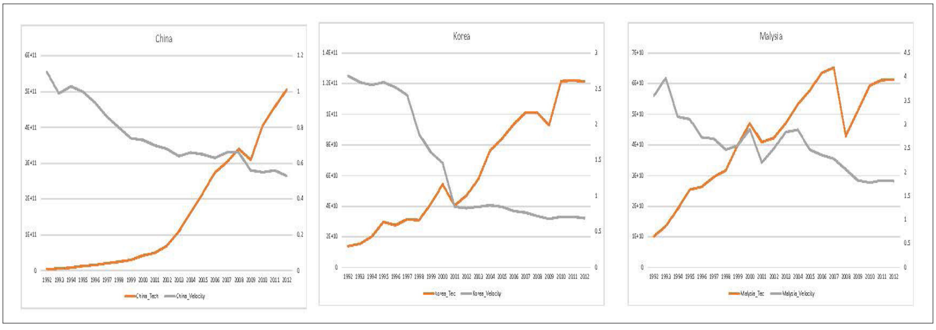
Year	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
Inflation rate (%)	1	1	4	0	1	0	2	4	1	6	6	22	16	10	17	25
Interest rate (%)	6	6	4	4	5	5	7	8	8	-	-	8-11	8-11	8-11	9-11	9-12

Source: Central bank of Iran

Although analyzing this structural change from the barter to money transactions is not the focus of this study, presenting a numerical example is helpful to illuminate the story. Assume that in time t1 the total nominal GDP is 1000 units where 500 units of which are traded by money and the other 500 units are barter transactions and also assume that in time t1 the stock of money is 250 units. According to the equation of quantity theory, the income velocity of money is 4 (1000/250=4) while the actual circulation of money should not be more than 2 (500/250=2) because only 500 units of relevant-to-GDP transactions are covered by money. Now assume that in time t2, the economy becomes more modern and all the transactions are covered by money and thus the total of 1000 units GDP are traded by money. Moreover, assume the stock of money increases to 500 units to cover the new monetized transactions. This implies that the income velocity of money has remained constant (1000/500=500/250=2).

2-1-3. Technical progress

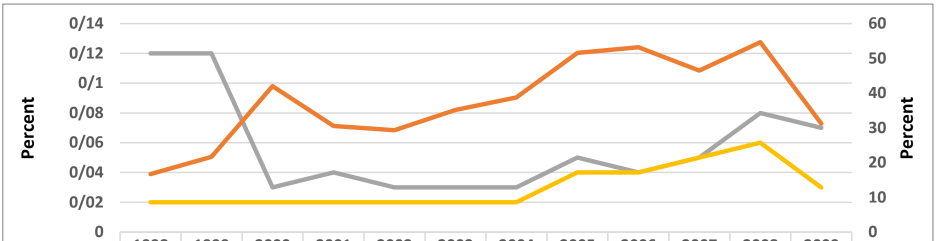
Technological progress is another situation where the equation of quantity theory may suggest a declining income velocity while the actual circulation of money is more and less constant. As economies move from producing primary and natural-resource based goods to more high-tech goods, for a given amount of nominal GDP, the number and nominal value of intermediary goods (and the number of associated transactions) increase. This results in a hike in the amount of money that is needed for covering all transactions (of final or intermediary goods and services). For some of the countries in East Asia, for instance, there are some stylized facts that reveal a high negative correlation between the growth of high-tech's production and the income velocity of money (as a residual item in the equation of quantity theory). Therefore, as the process of industrial production in these economies becomes deeper, more money is needed to cover the increased intermediary transactions, however the formula shows a decrease in the income velocity of money (see Figure 1).



Source: comtrade.un.org/data

Figure 1 (a, b, c)- High-tech exports and income velocity (these graphs need to be much larger, and have clearly labeled axis and improved titles)

In these countries, the ratio of irrelevant-to-GDP transactions to total transactions has also increased which corresponds to an increased transaction of intermediary goods and switching from natural-resource based goods to high-tech goods with high added-value - not to an increase in unproductive activities. This situation does not apply to the economy in Iran because in the recent decades, the production of high-tech goods hasn't experienced a considerable growth. The economy as a whole has not been diversified and has remained predominately natural-resource based (see Figure 2).



	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Korea	0/12	0/12	0/03	0/04	0/03	0/03	0/03	0/05	0/04	0/05	0/08	0/07
Japan	0/02	0/02	0/02	0/02	0/02	0/02	0/02	0/04	0/04	0/05	0/06	0/03
Iran	16/69	21/67	41/97	30/54	29/31	35/17	38/74	51/57	53/21	46/45	54/65	31/18

Year

Source: World Bank, World Data Bank, World Development Indication, Sep. 2013

Figure 2- Comparison of Natural resource share of GDP between Iran, South Korea and Japan, 1998 -2008 –

2-1-4. The charge accounts and the velocity

Prior to the mid1960s, the Iranian economy, consisted of many economic agents, including many farmers and their labors who received the credit from stores to buy goods until they received their incomes after harvest time. When buyers can delay their payments, the income velocity of money is greater than the case where they have to pay for goods in spot[1]. Therefore, the cash trade expansion is another case in which the formula shows a declining income velocity of money, while the actual circulation of money is on average constant. However, this case is not the focus of this study since from the second half of 1960s, in particular after the implementation of the land reforms, the traditional purchasing with delaying payments has rapidly been replaced by cash transactions. In addition, during the last two decades the credit cards and the modern trade credit have been expanded and this means that the circulation of money (and hence the income velocity of money) has been increasing.

2-2. Where has money gone?

The conclusion of the above discussion is that because of high inflation and interest rates the circulation of money has not been declining in Iran's economy. As long as the circulation of money isn't declining (or is assumed constant), if the ratio of irrelevant-to-GDP transactions to total transactions is constant, the ratio of money to GDP will be constant and thus the liquidity growth rate must be equal to the sum of inflation rate and real GDP growth. However, as mentioned before, when the liquidity growth is greater than the sum of inflation rate and real GDP growth, we can conclude that the liquidity has disproportionately been allocated to the irrelevant-to-GDP transactions (unproductive activities). A relevant question is that what activities and transactions have absorbed the extra liquidity? As mentioned before the unproductive activities include a very vast range from the illegal ones to those which are apparently productive but actually are not. Examining all of them in this paper is very difficult, or even due to the lack of data and statistical limitation is impossible. Therefore, this study focuses on real-estate activity (as this is perhaps the most important one) and how this sector has adversely affected Iran's economy in recent decades.

2-3. Real estate and money performance

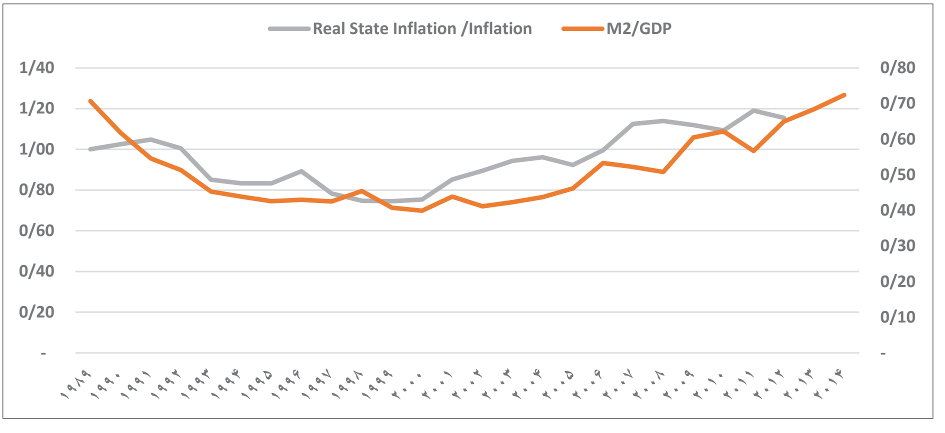
According to the Dutch disease theory, in natural-resource-based economies, like Iran, a proportion of the oil-boom revenues is spent on non-tradable goods (mainly services), which leads to an appreciation of the real exchange rate. This in turn draws resources out of tradable-goods sectors (primarily manufacturing) and into the non-tradable sector, to the extent that this tradable sector is exposed to international competition. Moreover, the increased profitability of a booming sector bids up the prices of factors of production (primarily wages and the cost of capital equipment), which results in a contraction of tradable sectors due to the higher costs of production.

1. For theoretic base of this see: Clower, Robert W., and Peter W. Howitt. "The transactions theory of the demand for money: A reconsideration" Journal of Political Economy 86, no. 3 (1978): 449-466.

This phenomenon may lead to an unbalanced growth across the sectors of the economy in favor of unproductive activities. When, for instance, the real estate sector is flooded with liquidity, its price index grows considerably faster than that of other sectors and yields higher profits, which in turn, attracts even more and more liquidity. Thus, in such a situation, real estate speculation expands very fast and the spiral of real estate price-money growth becomes more entwined. Recall Tobin's (1986) statement:

"We are throwing more and more of our resources, including the cream of our youth, into financial activities remote from the production of goods and services, into activities that generate high private rewards disproportionate to their social productivity."

This section focuses on the real estate sector (land and housing) which has absorbed a significant share of liquidity. In Iran's economy, there are some stylized facts implying that the real estate sector has deviated from its original function in recent decades. As Figure 3 shows, from 1989 to 2012, the ratio of real estate inflation to general inflation has fluctuated with the ratio of liquidity to GDP and this indicates that there is a dynamic interaction between liquidity and real estate inflation. (See Figure 3).



Source: Central bank of Iran

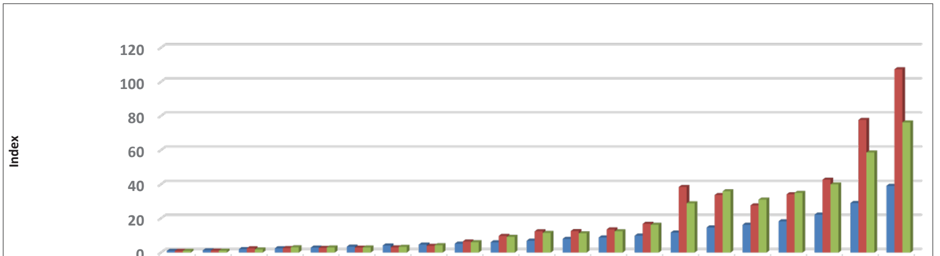
Figure 3- Liquidity and real state inflation have moved together

From 1989 to 2000, the ratios of M2[1]/GDP and real-estate inflation to general inflation have declined while both ratios have been increasing from 2001 to 2013. As mentioned before, assuming, because of inflation and interest rate status, the income velocity of money is constant, any increases in M2/GDP mean that the liquidity growth is greater than the sum of inflation rate and real GDP growth and vice versa. However, we believe that during the

1. Money (M1) includes currency and money in checking accounts (demand deposits). Traveler's checks are also a component of M1. Liquidity (M2) includes all of M1, plus savings deposits, time deposits like certificates of deposit, and money market funds.

downward trend of M2/GDP in some cases, circulation of money has increased due to the high inflation rates. In last three quarters of 1975 and first quarter of 1976, for instance, the wholesale inflation and CPI inflation rates were about 60% and 49.6% respectively. Based on the historical data and macroeconomic environment, we infer that as the M2/GDP declined from 1989 to 2000, either the ratio of irrelevant-to-GDP transactions to total transactions declined and circulation of money was constant or that ratio was constant but money circulation increased (or the former has declined and the latter has increased). However, we believe that when M2/GDP increased from 2001 to 2014, only the ratio of transactions changed. This would imply that the relationship between the ratio of irrelevant-to-GDP transactions to total transactions and M2/GDP is somewhat asymmetric.

As Figure 4 shows, in 2013 land and housing prices in Iran's economy were 107 and 76 times, respectively, more than they were in 1993, while the level of general prices has increased only 37 times more over the same 20 years.



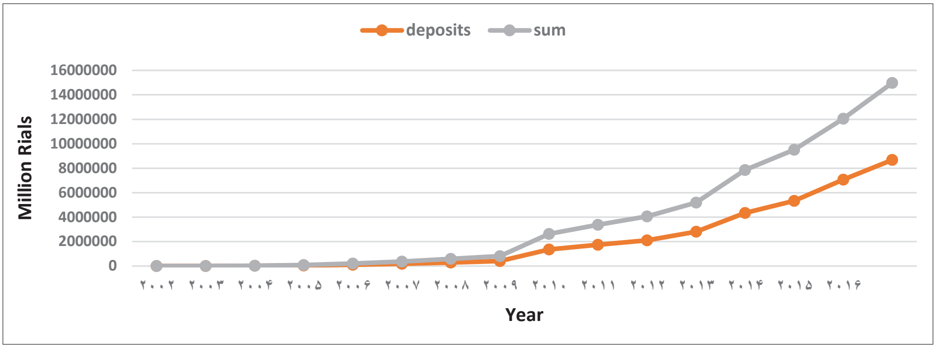
	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
General index*	1	1/356	2/022	2/489	2/911	3/444	4/133	4/667	5/2	6/022	6/956	8/022	8/844	9/911	11/71	14/69	16/27	18/29	22/22	29	39/09
Land Index	1	1/168	2/491	2/605	2/7	2/9	3/047	3/932	6/489	9/763	12/47	12/57	13/57	16/82	38/41	33/68	27/63	34/13	42/68	77/69	107/4
house index	1	1/135	1/822	3/087	2/995	2/995	3/365	4/284	6/038	9/168	11/51	11/22	12/47	16/26	28/83	35/88	31	34/93	39/94	58/6	76/23

Year

Source: Statistical center of Iran

Figure 4- Land prices and housing prices in Iran have increased 3 and 2 times more than general price over the past 20 years

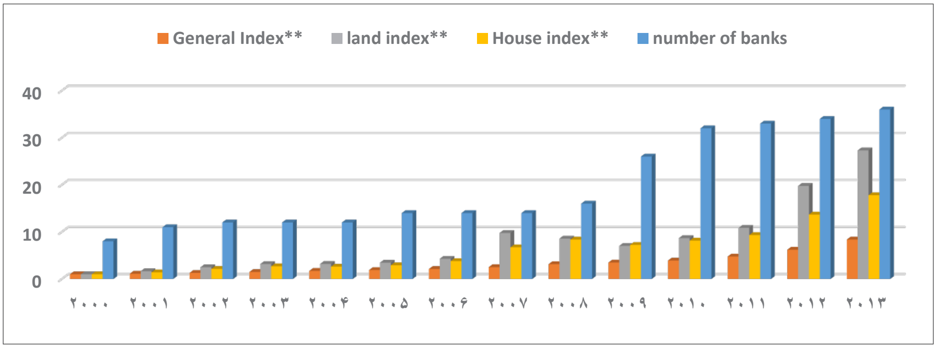
In other words, during this period, land and housing prices have increased 3 and 2 times more than the general prices. However, since the price indexes are the weighted average of prices across many regions, they do not reflect the actual variation and the extreme disproportionate changes in some regions of Tehran. The price of land, for instance, during the mentioned period in some neighborhoods of Tehran has increased more than one thousand times. As Figure 4 indicates, from 1993 to 2000 the growth of land and housing price indexes have been slower than the general price index while from 2000 to 2013 the formers have increased about 3.5 and 2.5 times more than the latter. In the first sub period, the relevant market forces have been main determinants of prices in the land and housing markets, but in the next sub period, the speculative activities have dominated the fundamental and relevant forces and have been the main determinant of land and housing prices. Thus, the speculative activities in land and housing markets, instead of facilitating the stability and growth of the whole economy, have actually been a drag on economic growth., By increasing the opportunity cost of productive activities and absorbing the limited resources, these real-estate activities have deviated from their primary function, and as such should be considered as unproductive activities. In addition, so called private banks were exactly established and expanded in the second sub-period; these banks are neither competitive nor have any transparent performance and were not established by the real private agents. Instead of improving the competitiveness of the financial sector, the emergence and fast expansion of such banks, strengthened the monopolistic powers in the overall economy and in particular that of the financial markets. Due to the lack of clear and transparent performance reports, the official accounts of these banks are not reliable for assessing the allocation of their resources to various economic activities. For example, the value of total deposits in the banks must be equal to the sum of their total lending and (required, precautionary and idle) reserves. However, in the case of these so-called private banks, the deposits are considerably lower than the other two items and this gap has been widening over time. (See Figure 5).



Source: Central bank of Iran

Figure 5- Divergent paths of the deposits and the sum of lending and reserves

This widening gap indicates that these banks have themselves been involved in the speculative, rent seeking and monopolistic activities (such as speculation in land, housing, foreign exchange, international trade, stocks, and gold markets). As Figure 6 demonstrates, we attribute the main component of this gap to speculative activities in land and housing markets, since there is a high correlation between the disproportionate appreciation of real estate values and the number of private banks.



Source: Statistical center of Iran

Figure 6- The presence of private banks and real estate prices have experienced a much faster growth than general prices.

In Iran's economy, speculation in land and housing markets has changed the main function of the real estate activities and has pushed them toward unproductive activities through increasing the interest rates and opportunity costs and absorbing a considerable fraction of total GDP at the expense of reduction in income of productive agents (entrepreneurs, workers, capital owners) and therefor putting pressure on the productive sector. Thus, as a result of such a performance, the real estate sector has actually triggered an overall deep economic recession and then itself has also fallen into a prolonged recession. The prevailing prices in land and housing markets are not affordable for many households and thus the existing recession in real estate sector cannot be simply resolved by self-correcting forces. The disproportionate change in land and housing prices relative to the wages and general prices is the root cause of this recession and correcting such a distortion is very difficult.

The nonproductive sector includes a very wide range of activities but, due to lack of reliable data, we mainly focus on speculation in land and housing markets as the most important component of unproductive activities. We hypothesize that the excess liquidity growth over nominal GDP has flooded to extra irrelevant-to-GDP transactions and as argued before, under the prevailing situation in Iran's economy, these transactions are mainly unproductive. Therefore, the difference between the liquidity growth and the nominal GDP growth (inflation rate plus real GDP growth) is considered as a proxy of unproductive activities. The purpose of this study is to show this proxy of unproductive activities affects the total GDP negatively. In fact, we consider this proxy as a negative input and put it in total production function and estimate its impact on total production using an econometrics method.

3. Empirical framework, data, estimation, and results

In this section, we specify the total production function, investigate the features of our data, estimate the model, conduct the related tests and finally present the results.

3-1. Model specification

The literature on productivity and growth is vast and we do not aim to contribute to debates on the productivity theories but instead trying to explain the most influential and important facts related to the developing economies such as Iran. As discussed before, the accumulation of production factor does not guarantee accelerating growth and prosperity unless institutional environment, rules of the game and prevailing relative returns are in favor of the productive activities. We specify a Cobb-Douglas functional form for the total production and modify it in such a way that includes the proxy of unproductive activities. This proxy can be considered as a negative input or productivity indicator that explains the slowdown of productivity and growth in Iran's economy:

$$Y_t = AK_t^{\alpha_1} L_t^{\alpha_2} e^{\alpha_3(m_t)} e^{u_t}$$

Where Y_t is total production of the economy, K_t is total stock of capital, is total labor, L_t is the difference between the liquidity growth and the nominal GDP growth, u_t is the stochastic residual term and , A,a_1, a_2 and a_3 are constant coefficients. By taking logarithm, we can transform this nonlinear equation to a linear one:

$$\ln Y_t = \ln A + \alpha_1 \ln K_t + \alpha_2 \ln L_t + \alpha_3 m_t + u_t$$

3-2. Data and stationary test

Time series data for these variables range from 1975 to 2024 and are annual observations. Before estimating the model, it is important to investigate whether the variables are stationary to avoid a potential spurious regression as discussed by Phillips (1986). If the first and second order moments of a time series are constant over the time it would be weakly stationary, otherwise it would be nonstationary. However, nonstationary time series could be transformed to stationary ones by taking the difference. To investigate if our time series, are stationary or not the augmented Dicky-Fuller test, commonly-used in econometric studies, is performed:

Table 4- Augmented Dicky-Fuller test

symbols	statistics	Critical points		
	ADF	1%	5%	10%
LnGDP	-0.6714	-3.5924	-2.9314	-2.6039
DLnGDP	-6.9290	-3.5924	-2.9314	-2.6039
LnK	-0.7324	-3.5924	-2.9314	-2.6039
DLnK	-1.9633	-2.6150	-1.9484	-1.6121
LnL	-2.0663	-3.5847	-2.9281	-2.6022
DLnL	-4.8451	-3.5858	-2.9297	-2.6030
m	-4.3199	-3.5847	-2.9281	-2.6022

Where Dx denotes the difference of variable X. As Table 4 shows, while the time series of m (liquidity growth) is stationary (integration of order zero i.e., I(0)), all other variables are nonstationary (integration of order one i.e., I(1) and thus, their first order differences are stationary. Therefore, we have to use such an econometric method that is appropriate for the variables with different orders of integration.

Granger and Newbold (1974) argued that if there are some nonstationary variables in a time series model, we would likely fall in the spurious regression implying that while the estimated coefficients are apparently significant, they are, in fact, insignificant. However, Engle and Granger (1987) showed that, for example, if two time series variables are individually integrated of order one and a linear combination of them is integrated of order zero then they would be cointegrated of order zero implying the existence of at least one vector of coefficients that represents a long-run relationship between the variables.

3-3. Cointegration test

Before using the Autoregressive-Distributed Lag (ARDL) approach, we examine the existence of long run relationships(s) between our variables using a Johansen test for cointegration. According to the Schwartz criterion, the most appropriate specification for testing the cointegration includes an intercept and a trend … As the results in Table 5 show, the results of trace and eigenvalue tests indicate that there exists at least one cointegrating vector among the time series variables of our model that validates the existence of a long run relationship between them.

Table 5- Johansen Test for Cointegration,

Trace test				Maximum Eigenvalue test			
Null hypothesis	Alternative hypothesis	Statistics	Critical points of 95%	Null hypothesis	Alternative hypothesis	Statistics	Critical points of 95%
r=0	r≤1	26.6063	24.2759	r=0	r=1	18.6284	17.7930
r≤1	r≤2	7.9779	12.3209	r≤1	r=2	7.2138	11.2248
r≤2	r≤3	0.7640	4.1299	r≤2	r=3	0.7640	4.1299

If all of the time series variables are integrated of same order, maximum likelihood estimation method of Johansen (1991) would be the best approach for testing of cointegration vector. However, since our variables are integrated of different orders the ARDL model of Pesaran and Shin (1997) – is more appropriate. An additional advantage of ARDL approach is that it captures the short run dynamics as well as the long run relations. Since the (asymptotic) distribution of F statistics is not standard, Pesaran and Shin (1997) have themselves created an adjusted F statistics by simulation for testing cointegration and calculated the critical values that correspond to the number of the regressors and the existence of intercept and trend in the model.

3-4. Estimating the model

After validating the existence of a long run relationship between the variables we estimate the ARDL model. Considering the size of our sample (1975-2024), we use the Schwartz criterion to choose the optimum number of lags. The results of the estimated ARDL model are shown in Table 6. The estimated coefficients of capital stock (LK) and labor (LL) are statistically significant and have the signs that were theoretically expected. The estimated coefficient of the proxy of unproductive activities, m, is also significant with a negative sign. This confirms our hypothesis that the unproductive activities have a negative impact on the GDP. Thus, the liquidity growth in Iran's economy has been a drag on the economic growth.

Table 6- The results of Autoregressive Distributed Lag Estimates

The optimum lags for the independent variable and the regressors are 2, 0, 1, and 0 respectively				Independent Variable: LGDP
The names Of variables	Coefficients	Standard error	T statistics	probability
LGDP(-1)	0.5480	0.1375	3.9831	0.003
LGDP(-2)	-0.2674	0.1017	-2.6290	0.012
LK	1.9364	0.5054	3.8308	0.000
LK(-1)	-1.5680	0.4389	-3.5721	0.001
LL	0.4789	0.1108	4.3193	0.001
m	-0.1986	0.0637	-3.1180	0.003
C	-3.0727	0.6507	-4.7219	0.000
R squared = 0.989, R-bar squared = 0.9875 DW statistic = 1.8788 F statistic = 571.1183				

The statistics of the diagnostic tests related to this estimation are also shown in Table 7. The diagnostic tests examine if the estimated model satisfies the classical assumptions for the regression and its residuals. For all of these tests, the null hypotheses correspond to the violation of these assumptions, so the rejection of the null hypotheses means the estimated model meets the classical requirements. All null hypotheses related to serial correlation, functional form, normality and heteroscedasticity are rejected and thus the estimated results are robust.

Table 7- Diagnostic tests

classic assumption violation H0	Serial correlation	Functional form		normality	heteroscedasticity	
statistics	F	Chi2	F	Chi2	Chi2	F
value of statistic	0.2279	0.95589	0.73003	0.14419	9.970	1.846
probability	0.1681	0.328	0.401	0.930	0.126	0.116

The results of testing for the existence of a relationship among the variables at their level in ARDL model are presented in Table 8. Here, the null hypothesis is the lack of a long run relation between the variables. According to Pesaran's F statistic (2001), if calculated F is above the upper bound, null hypothesis of no relation is rejected, but if it is below the lowest bound the null hypothesis cannot be rejected and if it lies between the bounds, the test will be inconclusive. As Table 8 shows, the calculated F (8.7399) is above the upper bound, so there is a relationship among the variables at their level.

Table 8- Testing for existence of a relationship among the variables at their level in the ARDL model

F statistic	95% lower bound	95% upper bound	90% lower bound	90% upper bound
8.7399	2.79	3.67	2.37	3.2

Table 9- Estimated long run coefficients using the ARDL Approach

Independent variable is LGD 44 observations used for estimation from 1975 to 2024				
regressors	coefficients	Standard error	T statistic	probability
LK	0.5121	0.1208	4.2370	0.000
LL	0.6658	0.1470	4.5293	0.000
m	-0.2761	0.0986	-2.7991	0.007
C	-4.2714	0.6568	-6.5026	0.000

The estimated long run coefficients of the model are shown in Table 9. Capital (LK) and labor (LL) have positive long run and statistically significant effects on the GDP. The estimated long run coefficient for the proxy of unproductive activities, m, is significant and negative. This means such activities are a drag on the productivity and GDP. The results of the estimated ARDL model clearly show that unproductive activities limit the economic growth both in the long and short-runs.

The resulting error correction form of the selected model is specified as below:

$$\Delta LGDP_t = -\varphi(ecm_{t-1}) + \gamma_1 \Delta LGDP_{t-1} + \gamma_2 \Delta LK_t + \gamma_3 \Delta LL_t + \gamma_4 \Delta M_t + \varepsilon_t$$

where ecm_{t-1} is the error correction term, φ is the coefficient of adjustment speed and s are the short run coefficients. The estimated value of φ in table 10 indicates that about 72% of error (deviation from the equilibrium) would be corrected in each period. In other words, if a shock drives the model away from the equilibrium, about 72% of deviation is corrected in the first period.

Table 10- Error Correction coefficient of adjustment speed for the Selected ARDL Model

Dependent variable is dLGDP				
Regressors	coefficient	Standard error	T statistic	probability
ecm(-1)	-0.7193	0.1033	-6.9587	0.000

To validate the stability of the regression, we conduct the CUSUM (Cumulative Sum of Recursive Residuals) and CUSUMSQ (Cumulative Sum of Squares of Recursive Residuals) stability tests for the estimated ARDL model. As Figure7 indicates, the values of the test statistics and critical values at 5% significance level have been plotted and since the value of the statistics are between the upper and lower bounds of that critical values, the stability of the regression cannot be rejected.

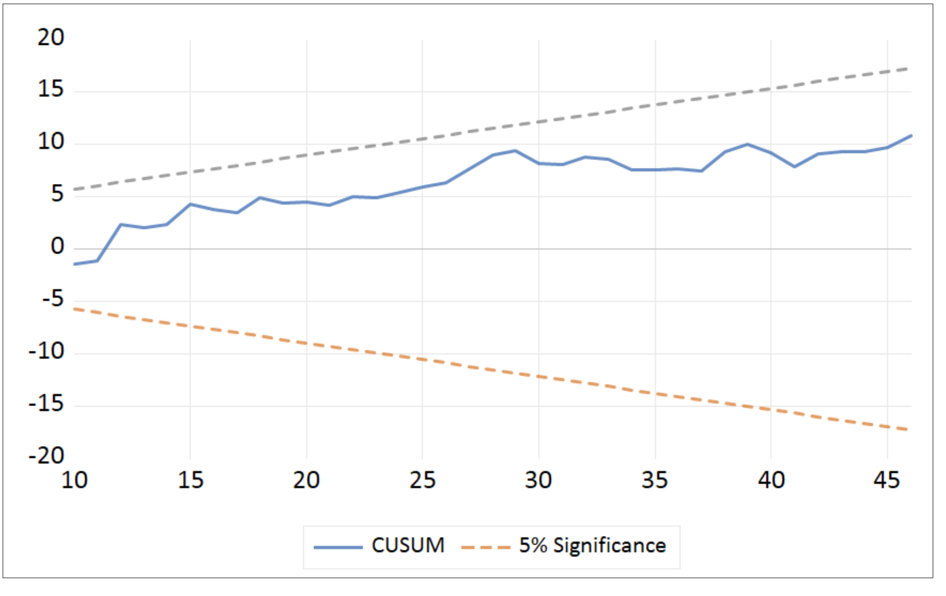


Figure 7- The stability test for the estimated ARDL model

4. Conclusions and implications

This paper has argued that in recent decades, the actual circulation of money in the Iranian economy has on average been constant, despite although the formula (the quantity theory of money) indicating that circulation of money has been declining. To explain this paradox, we discussed that the ratio of irrelevant-to-GDP transactions to total transactions has increased. Thus, the additional money corresponding to the difference between the liquidity growth and the nominal GDP growth rates has instead been exclusively flooded into unproductive activities. Economically unproductive sectors in Iran includes a vast range of activities such as speculation in land, housing, foreign exchange, international trade, stocks, and gold markets. All unproductive activities can be characterized by having a high rate of return without creating any real economic value. These unproductive activities absorb the limited resources and increase the opportunity costs for productive investments, and should be considered to be a drag on the economic growth and productivity of the country. Due to lack of data, we examined the real estate sector and showed that speculation in the land and housing markets and continuous dramatic increase in their prices correspond to the increases in liquidity to GDP ratio. Finally, by considering the difference between the liquidity growth rate and the sum of inflation and real GDP growth as a proxy of unproductive activities, we specified and estimated a macro-level production function which includes that proxy, using an econometric method. Our hypothesis was that the excess liquidity growth over the nominal GDP growth has been flooded into irrelevant-to-GDP transactions which are unproductive and thus has negatively affected both productivity and economic growth in Iran. The results found that the proxy for unproductive activities has a negative and statistically significant impact on the total production in Iran's economy implying that unproductive activities are a drag on both the economic growth and productivity. Diverting the resources from productive to unproductive activities is due to their relative returns and pay-offs matrix. The immediate implication of our results for Iran's economy is that economic-social planners and policy makers should know they couldn't accelerate the economic growth and achieve to a high productivity unless correct the rules and the pay-offs of the game. This would certainly require some institutional reforms in addition to reorientation of some of the existing socio-economic policies in Iran.

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Natural Gas Supply-Demand Imbalance, Energy Security, and Industrial Competitiveness in Iran

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Abstract

Energy security is a critical prerequisite for sustainable economic and industrial development. In Iran, it is of particular importance due to the dominant role of natural gas in the national energy mix. This study examines the structure of energy consumption, analyzes the natural gas supply–demand imbalance, and evaluates its implications for energy security and the competitiveness of energy-intensive industries. The research adopts an applied descriptive–analytical approach and utilizes data obtained from Iran's Energy Balance Sheets, reports of the Ministry of Petroleum, the Ministry of Energy, the National Iranian Gas Company, the Iranian Parliament Research Center, the International Energy Agency (IEA), and the financial statements of publicly listed companies. The findings reveal that the extensive dependence of the residential, power generation, and industrial sectors on natural gas, together with rapid demand growth, investment constraints, infrastructure limitations, and high energy intensity, has significantly exacerbated the gas supply–demand imbalance and increased vulnerabilities in the country's energy security. The analysis further indicates that energy-intensive industries, particularly the petrochemical, steel, and cement industries particularly the petrochemical, steel, and cement industries, are highly exposed to gas supply disruptions. Such constraints result in production losses, reduced export performance, higher operating costs, and an erosion of competitive advantages in both domestic and international markets. The study also identifies several policy measures for mitigating the imbalance, including reforming the natural gas pricing system, improving energy efficiency, expanding the deployment of renewable energy, encouraging industrial participation in upstream gas field development, and implementing effective demand-side management programs. The study concludes that the Natural Gas Supply–Demand Imbalance in Iran is not merely an energy-sector concern but a strategic challenge with far-reaching consequences for industrial development, economic growth, and long-term energy resilience.

Keywords: Natural Gas Supply; Energy Security; Energy-Intensive Industries; Energy Efficiency

چکیده

امنیت انرژی پیش‌شرط بنیادین توسعه پایدار صنعتی و اقتصادی است؛ امری که در ایران به‌دلیل سهم مسلط گاز طبیعی در سبد انرژی کشور اهمیتی دوچندان دارد. این پژوهش کاربردی با رویکردی توصیفی تحلیلی و اتکا به داده‌های ترازنامه انرژی، مراجع رسمی داخلی و آژانس بین‌المللی انرژی، به واکاوی ساختار مصرف، ناترازی گاز و پیامدهای آن بر امنیت انرژی و رقابت‌پذیری صنایع انرژی‌بر می‌پردازد. یافته‌ها نشان می‌دهد وابستگی مفرط بخش‌های خانگی، نیروگاهی و صنعتی به گاز، هم‌زمان با رشد فزاینده تقاضا، شدت مصرف بالا و تنگناهای سرمایه‌گذاری و زیرساختی، کسری گاز را تشدید کرده است. کانون این آسیب‌پذیری متوجه صنایع انرژی‌بر، به ویژه پتروشیمی، فولاد و سیمان، است که با قطعی‌های دوره‌ای گاز مواجه‌اند؛ امری که به توقف تولید، افت صادرات، جهش هزینه‌های سربار و فرسایش مزیت‌های رقابتی انجامیده است. به منظور مهار این بحران، راهکارهایی نظیر اصلاح نظام قیمت‌گذاری، ارتقای بهره‌وری، توسعه تجدیدپذیرها، مدیریت تقاضا و مشارکت صنایع در بالادست میادین گازی پیشنهاد می‌شود. در نهایت، این مطالعه تصریح دارد ناترازی گاز در ایران فراتر از یک چالش فنی در بخش انرژی، تهدیدی راهبردی برای تاب‌آوری اقتصادی و پیشران‌های صنعتی کشور است.

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1. Introduction

Energy is widely recognized as one of the most critical foundations of economic, industrial, and social development worldwide. Reliable and sustainable access to energy is a prerequisite for economic growth, improved public welfare, and the achievement of sustainable development goals. In recent decades, population growth, industrial expansion, rapid urbanization, and the proliferation of advanced technologies have significantly increased global energy demand. Under these circumstances, energy security has become a major concern for governments, policymakers, and economic stakeholders, occupying a central position in national strategic planning. Any disruption in energy supply or increase in instability within energy markets can have far-reaching consequences for production, employment, economic growth, and national security (BP, 2023; IHS Markit, 2023; U.S. Energy Information Administration [EIA], 2023).

The concept of energy security has undergone substantial transformation over the past several decades. Initially, energy security was primarily associated with the continuous supply of petroleum resources and guaranteed physical access to fossil fuels. However, successive energy crises, increasing volatility in energy prices, growing environmental concerns, and emerging challenges related to climate change have considerably broadened its scope. Today, energy security extends beyond the mere availability of energy resources and encompasses several dimensions, including the diversification of energy sources, the reliability of production and transmission infrastructure, economic sustainability, resilience to disruptions and crises, environmental considerations, and equitable access to energy services. Consequently, international organizations such as the International Energy Agency and the World Energy Council have developed various frameworks and indicators to assess and compare the energy security performance of countries (Energy Outlook Assessment [EOA], 2023; IHS Markit, 2023).

One of the most widely recognized frameworks in this field is the World Energy Council's Energy Trilemma Index, which evaluates countries' performance based on three core dimensions: energy security, energy equity, and environmental sustainability. This framework highlights that achieving sustainable energy security requires balancing reliable access to energy, environmental protection, and the fulfillment of economic and social needs. In other words, countries that rely solely on the abundance of energy resources while neglecting energy diversification, efficiency improvements, and environmental sustainability are likely to face significant energy security challenges in the long term (Energy Outlook Assessment [EOA], 2023).

Iran, endowed with vast oil and natural gas reserves, has long been considered a major player in the global energy market. Despite this strategic advantage, the country's energy production and consumption structure remain heavily dependent on fossil fuels, particularly natural gas. According to official statistics, more than 97% of Iran's primary energy supply is derived from oil and natural gas, while the contribution of renewable and other low-carbon energy sources to the national energy mix remains limited. Although this dependence has historically provided relatively affordable and reliable access to energy for various sectors of the economy, it has also created significant structural vulnerabilities within the country's energy system. The concentration of energy supply on a limited range of resources reduces the flexibility of the energy sector and increases its exposure to supply disruptions, investment constraints, and fluctuations in domestic demand. Consequently, maintaining the sustainability and reliability of energy supply has become an increasingly important challenge for policymakers and energy planners in Iran (BP, 2023; National Iranian Oil Company [NIOC], 2022; U.S. Energy Information Administration [EIA], 2023).

An examination of Iran's energy balance indicates that natural gas constitutes the backbone of the country's energy system, with the residential, industrial, power generation, and petrochemical sectors exhibiting a high degree of dependence on this energy carrier. In recent years, increasing domestic consumption, growing demand across various sectors, and investment constraints associated with international sanctions have transformed the natural gas supply–demand imbalance into one of the most significant challenges facing Iran's energy sector. This imbalance has been particularly pronounced during the colder months of the year, leading to fuel supply restrictions for industries and power plants and imposing substantial economic costs on the productive sector. Furthermore, the heavy reliance of the country's power plants on fossil fuels, particularly natural gas, has increased the vulnerability of electricity generation to disruptions in gas supply. Consequently, any interruption or limitation in the availability of natural gas can directly affect electricity supply security and undermine the reliability of the national power system (Ministry of Petroleum, 2022; National Iranian Gas Company [NIGC], n.d.; National Iranian Oil Company [NIOC], 2022).

The energy security literature commonly highlights four principal dimensions: availability, reliability, affordability, and environmental sustainability (IHS Markit, 2023).

In addition to the issue of dependence on fossil fuels, Iran's energy intensity remains considerably higher than that of many countries around the world. A substantial portion of the country's energy production is lost during the processes of extraction, conversion, transmission, and final consumption, indicating significant potential for improvements in energy efficiency. The continuation of this trend not only exacerbates energy imbalances but also imposes considerable economic and environmental costs on the country, potentially undermining the long-term competitiveness of its industries (Energy Outlook Assessment [EOA], 2023; National Productivity Organization of Iran, 2023).

Among the various sectors of the economy, mining and mineral-based industries are among the largest energy consumers in Iran. Industries such as steel, cement, copper, aluminum, ceramics and tiles, and other mineral-processing sectors account for a substantial share of the country's natural gas and electricity consumption. Since energy constitutes a critical production input in these industries, any constraint on the supply of energy carriers can significantly affect production levels, operating costs, competitiveness, and profitability. In recent years, supply restrictions resulting from natural gas shortages and electricity deficits during different seasons have further highlighted the importance of energy demand management and the diversification of energy supply sources within these industries. These challenges underscore the need for policies aimed at enhancing energy efficiency, improving supply reliability, and strengthening the resilience of energy-intensive industrial sectors (National Iranian Gas Company [NIGC], n.d.; National Productivity Organization of Iran, 2023).

From a risk management perspective, the heavy concentration of national energy consumption around a single energy carrier, particularly natural gas, has increased the vulnerability of Iran's economy to both domestic and external shocks. International sanctions, investment constraints, the aging of parts of the energy infrastructure, growing domestic demand, and the impacts of climate change are among the factors that may jeopardize the security of energy supply. Therefore, identifying the structure of energy consumption, assessing the degree of dependence of different economic sectors on various energy carriers, and analyzing the implications of this dependence are essential prerequisites for developing effective strategies to enhance national energy security (Ministry of Petroleum, Vice Presidency for Planning, n.d.; Parliament Research Center of the Islamic Republic of Iran, n.d.).

Accordingly, this study focuses on Iran's energy balance structure and examines energy consumption patterns in energy-intensive industries in order to analyze the current situation and identify the principal challenges facing the country's energy security. The research seeks to provide a comprehensive understanding of the existing dependencies within the energy system, clarify the role of energy-intensive industries in national energy consumption, and contribute to the development of effective policy measures aimed at strengthening energy resilience, improving energy efficiency, and enhancing the overall security and sustainability of the country's energy system.

2. Research Methodology

This study is applied in terms of its objective and adopts a descriptive–analytical research design. The study population consists of Iran's energy-intensive industries, among which the petrochemical, steel, and cement sectors were selected as representative case studies. The data utilized in this research were collected from the following sources:

- Iran's Energy Balance Sheets
- Reports published by the Ministry of Petroleum
- Reports of the Ministry of Energy
- Reports of the National Iranian Gas Company (NIGC)
- Publications of the Iranian Parliament Research Center
- Reports of the International Energy Agency (IEA)
- Financial statements of publicly listed companies

Data were analyzed using a policy analysis framework and a trend-comparative approach (National Iranian Oil Company [NIOC], 2022; National Iranian Gas Company [NIGC], n.d.; Parliament Research Center of the Islamic Republic of Iran, n.d.; Securities and Exchange Organization of Iran [CODAL], n.d.; Tavanir, 2023).

3. Natural Gas Status in the World and Iran

Natural gas is one of the most important energy carriers worldwide and, due to its lower environmental impact compared with other fossil fuels, plays a significant role in energy supply and the transition toward a low-carbon economy. According to 2023 statistics, the United States, with production exceeding 1,070 billion cubic meters, was the world's largest producer of natural gas, followed by Russia and Iran in second and third place, respectively. In terms of consumption, the United States, Russia, China, and Iran rank among the largest natural gas consumers globally.

With approximately 6% of global natural gas production and consumption, Iran occupies a prominent position in the international energy market. However, the majority of the country's natural gas production is consumed domestically. Rapid growth in demand, particularly in the residential, power generation, and industrial sectors, has intensified the natural gas supply–demand imbalance in recent years. This situation has created significant challenges for the country's energy security and has further underscored the necessity of improving energy efficiency, strengthening demand-side management, and implementing effective energy consumption policies (BP, 2023; U.S. Energy Information Administration [EIA], 2023).

3.1. Concentration of Global Natural Gas Reserves

Global natural gas reserves are unevenly distributed, with a substantial share concentrated in a limited number of countries. Iran, Russia, Qatar, and Turkmenistan collectively possess nearly half of the world's proven natural gas reserves. This high degree of concentration has enhanced the geopolitical significance of natural gas and positioned countries with large reserves as key actors in global energy security. Among the world's gas fields, the South Pars–North Dome field, shared between Iran and Qatar, is recognized as the largest known natural gas field in the world and contains a significant proportion of global gas reserves (BP, 2023; U.S. Energy Information Administration [EIA], 2023).

3.2. The South Pars Gas Field and Its Importance for Iran

The South Pars gas field is Iran's most important source of natural gas supply and the largest gas field in the world. It provides more than 70% of the country's natural gas consumption and plays a crucial role in electricity generation, feedstock supply for the petrochemical industry, mineral-processing industries, and residential energy consumption.

The development of this field over the past two decades has significantly contributed to increasing Iran's gas production capacity and expanding the country's energy infrastructure. Despite these advantages, the heavy dependence of the national energy system on a single shared field represents a strategic risk. Any decline in production or disruption in the operation of South Pars could adversely affect multiple sectors of the economy and jeopardize national energy security (National Iranian Gas Company [NIGC], n.d.; South Pars Gas Complex [SPGC], n.d.).

3.3. A Comparison of Iran and Qatar in Developing the Shared Gas Field

Although Iran and Qatar share the world's largest natural gas field, the two countries have followed markedly different development paths. Through substantial foreign investment, access to advanced technologies, and the expansion of its liquefied natural gas (LNG) industry, Qatar has become one of the world's leading natural gas exporters. In contrast, the development of South Pars in Iran has progressed more slowly due to investment constraints and the impact of international sanctions. This divergence demonstrates that the mere possession of abundant energy resources is not sufficient to secure economic benefits. Rather, the effective management, investment, and utilization of energy resources play a decisive role in creating economic value, strengthening competitiveness, and enhancing energy security (International Gas Union [IGU], 2022; South Pars Gas Complex [SPGC], n.d.).

4. Indicators and Trends of Natural Gas Consumption in Iran

4.1. Energy Intensity and Energy Transition

Energy intensity is one of the most important indicators for assessing energy efficiency and is measured as the ratio of energy consumption to gross domestic product (GDP). According to international reports, Iran's energy intensity is approximately 85% higher than the global average, reflecting high levels of energy consumption and relatively low efficiency across various sectors of the economy. Factors such as extensive energy subsidies, low energy prices, and the large share of energy-intensive industries are among the primary causes of this situation. Furthermore, Iran's position in the Energy Transition Index remains below the global average, with little noticeable improvement in recent years. This highlights the need for comprehensive energy policy reforms, the adoption of advanced technologies, and greater efficiency improvements throughout the energy sector (Energy Outlook Assessment [EOA], 2023; National Productivity Organization of Iran, 2023).

4.2. Trends in Natural Gas Consumption and Supply–Demand Imbalance

Natural gas is the dominant energy carrier in Iran and supplies a substantial share of the country's residential, industrial, and power generation energy needs. Despite significant growth in natural gas production in recent years, rapidly increasing consumption has led to a persistent gas supply–demand imbalance. An examination of consumption trends during the 2010s indicates that natural gas demand expanded at a faster rate than supply capacity, gradually widening the gap between production and consumption. One of the defining characteristics of natural gas consumption in Iran is its pronounced seasonal fluctuation. During the colder months of the year, residential gas demand rises sharply, often resulting in supply constraints for industries and power plants. This situation imposes significant economic costs, including reduced industrial output and increased energy supply expenditures (Ministry of Petroleum, Vice Presidency for Planning, n.d.; National Iranian Gas Company [NIGC], n.d.; Parliament Research Center of the Islamic Republic of Iran, n.d.).

4.3. Future Outlook for Natural Gas Consumption

Forecasts of future natural gas supply and demand suggest that, if current trends continue, Iran's gas deficit is likely to increase substantially in the coming years. Conversely, the implementation of energy conservation measures, improvements in energy efficiency, and the gradual reform of pricing policies could significantly mitigate this imbalance. Therefore, effective demand-side management and the reduction of energy intensity are among the most critical requirements for maintaining long-term energy security and ensuring the sustainability of the country's energy system (Ministry of Petroleum, Vice Presidency for Planning, n.d.; Parliament Research Center of the Islamic Republic of Iran, n.d.; Planning and Budget Organization of Iran, 2023).

5. Impacts of Natural Gas Imbalance on Industry and the Production Sector

In recent years, the natural gas supply–demand imbalance has emerged as one of the most significant challenges facing Iran's industrial and energy sectors. Constraints in natural gas supply, particularly during the colder months of the year, have not only threatened energy security but have also imposed substantial economic costs on the country's major energy-intensive industries (Ministry of Petroleum, Vice Presidency for Planning, n.d.; Parliament Research Center of the Islamic Republic of Iran, n.d.).

5.1. Impact of Natural Gas Imbalance on the Petrochemical Industry

The petrochemical industry, as one of Iran's most important sources of export revenue, is highly dependent on natural gas. This dependence is particularly pronounced in methanol, ammonia, and urea production facilities, where natural gas serves not only as an energy source but also as the primary feedstock. In recent years, winter gas shortages have led to production disruptions and reduced profitability in many gas-based petrochemical plants. In contrast, facilities utilizing more diversified feedstocks have been less vulnerable to gas supply constraints. These findings suggest that the persistence of gas imbalances could significantly undermine the competitiveness and revenue-generating capacity of Iran's petrochemical industry (National Iranian Gas Company [NIGC], n.d.; National Petrochemical Company [NPC], n.d.; Securities and Exchange Organization of Iran [CODAL], n.d.).

5.2. Impact of Natural Gas Imbalance on Electricity Generation

The power generation sector is one of the largest consumers of natural gas in Iran, with the majority of the country's electricity produced by gas-fired thermal power plants. During periods of gas shortages, power plants are often forced to rely on alternative fuels such as diesel fuel and fuel oil (mazut). While this substitution ensures continued electricity generation, it increases production costs and generates considerable environmental impacts. Moreover, limitations in fuel supply can compromise the stability of the electricity grid and increase the risk of widespread power outages, thereby affecting both economic activities and public welfare (National Iranian Gas Company [NIGC], n.d.; Parliament Research Center of the Islamic Republic of Iran, n.d.; Tavanir, 2023).

5.3. Vulnerability of Energy-Intensive Mineral Industries

Mineral-based industries, including steel, cement, aluminum, and ferroalloy production, are among the largest energy consumers in Iran. In addition, the petrochemical sector is the country's largest consumer of natural gas feedstock. Gas supply restrictions have resulted in lower production of methanol, urea, and ammonia, reducing not only corporate profitability but also national export revenues.

The steel industry is particularly vulnerable to gas shortages, as more than 80% of Iran's steel production is based on the direct reduction process, which relies heavily on natural gas. Consequently, winter gas curtailments have led to reductions in crude steel production and exports. Similarly, the cement industry, one of the most energy-intensive sectors of the economy, faces increased production costs and significant environmental consequences when alternative fuels are used.

Analysis of energy consumption data for Iran's mineral industries indicates that the steel sector alone accounts for approximately 62.7% of total natural gas consumption within this group, while the cement industry represents about 32.3%. This high concentration of energy use means that natural gas imbalances directly affect the performance of strategically important industries. In practice, supply constraints typically result in reduced gas allocations to steel and cement producers, thereby limiting production capacity, exports, and employment opportunities.

From the perspective of industrial economics, this pattern reflects the strong dependence of industrial competitiveness on a subsidized production input. Such competitiveness has largely been built on access to inexpensive energy rather than on innovation, technological advancement, or productivity improvements. Consequently, when gas supply imbalances emerge, the competitive advantage of these industries is significantly weakened, exposing structural vulnerabilities within the country's industrial development model (National

Petrochemical Company [NPC], n.d.; Securities and Exchange Organization of Iran [CODAL], n.d.; Tavanir, 2023).

6. Energy Policy and the Energy Business Model in Iran

The natural gas imbalance in Iran is not merely the result of increasing consumption or production constraints; rather, it is deeply rooted in the country's energy policy framework and business model. Over the past decades, Iran's economy has been heavily dependent on revenues generated from oil and natural gas, and this dependence has significantly shaped the country's economic and industrial policies. Within this context, subsidized energy pricing has provided short-term support to consumers and industries; however, in the long run, it has contributed to rising demand, weakened investment incentives, and exacerbated imbalances within the energy sector. Furthermore, the development of Iran's energy industry has faced numerous challenges, including investment constraints, international sanctions, aging infrastructure, and the absence of an efficient financing system. These factors have prevented energy supply growth from keeping pace with increasing demand, resulting in a widening gap between production and consumption. Consequently, energy imbalance has evolved from a purely technical issue into a broader economic and strategic challenge (Ministry of Petroleum, Vice Presidency for Planning, n.d.; Parliament Research Center of the Islamic Republic of Iran, n.d.; Planning and Budget Organization of Iran, 2023).

In recent years, policymakers have sought to address this challenge through the gradual adjustment of natural gas prices for industrial consumers, the implementation of energy efficiency and conservation programs, and the establishment of energy intensity reduction targets within the Seventh National Development Plan. Nevertheless, the effectiveness of these measures depends on achieving an appropriate balance among three key objectives: energy security, industrial competitiveness, and economic sustainability (National Productivity Organization of Iran, 2023; Planning and Budget Organization of Iran, 2023).

An examination of Iran's energy business model indicates that the factors contributing to energy imbalance can be categorized into demand-side and supply-side drivers. On the demand side, low energy prices, inefficient consumption patterns, and high energy intensity have accelerated the growth of energy demand. On the supply side, investment limitations, restricted access to advanced technologies, and the limited economic attractiveness of energy projects have constrained the expansion of production capacity. The continuation of these conditions poses a significant threat not only to energy security but also to economic growth, industrial production, and the country's foreign exchange earnings (Ministry of Petroleum, Vice Presidency for Planning, n.d.; Parliament Research Center of the Islamic Republic of Iran, n.d.).

Therefore, transitioning toward a sustainable energy business model requires the gradual reform of energy pricing mechanisms, improvements in energy efficiency, increased investment, technological advancement, and the diversification of energy sources. Achieving these objectives can contribute to reducing the natural gas imbalance while simultaneously enhancing energy security and strengthening the resilience of the national economy (Energy Outlook Assessment [EOA], 2023; Planning and Budget Organization of Iran, 2023).

7. Natural Gas Imbalance and Industrial Competitiveness

Industrial competitiveness is a function of production costs, productivity, product quality, and the ability to ensure a stable and reliable supply. The natural gas supply–demand imbalance adversely affects all four of these factors.

The main consequences of the gas imbalance include:

- Increased production costs;
- Reduced capital productivity;
- Lower operational capacity of industrial facilities;
- Higher investment risk; and
- Declining export performance.

As a result, the competitive advantage of Iranian industries in global markets is weakened (Energy Outlook Assessment [EOA], 2023; Parliament Research Center of the Islamic Republic of Iran, n.d.; Planning and Budget Organization of Iran, 2023; Securities and Exchange Organization of Iran [CODAL], n.d.)

8. Proposed Solutions for Securing Energy Supply in Energy-Intensive Industries

An assessment of the natural gas supply–demand imbalance indicates that addressing this challenge requires a combination of short-term, medium-term, and long-term measures. Short-term solutions are primarily aimed at crisis management and maintaining production continuity, whereas medium- and long-term strategies focus on enhancing the sustainability of energy supply and reducing industrial dependence on natural gas.

8.1. Short-Term Solutions

The most important short-term measures include underground natural gas storage, the production and storage of synthetic natural gas (SNG), the utilization of alternative liquid fuels, and the limited development of solid fuel alternatives. Although these measures can be implemented relatively quickly, they are not capable of fundamentally resolving the gas imbalance and mainly serve to mitigate the adverse effects of supply shortages and energy crises (International Gas Union [IGU], 2022; Ministry of Petroleum, Vice Presidency for Planning, n.d.; Parliament Research Center of the Islamic Republic of Iran, n.d.).

8.2. Medium-Term Solutions

In the medium term, key measures include the recovery and utilization of flare gas, the optimization of energy consumption in buildings and industrial facilities, the implementation of industrial energy audits, and the reform of energy pricing and tariff structures. These initiatives can contribute to reducing natural gas consumption, improving energy efficiency, and partially alleviating the gap between energy supply and demand (National Productivity Organization of Iran, 2023; Planning and Budget Organization of Iran, 2023).

8.3. Long-Term Solutions

Long-term strategies encompass the expansion of renewable energy sources, industrial investment in oil and gas field development, the establishment of energy-saving certificate markets, the production and storage of liquefied natural gas, the adoption of hydrogen technologies in the steel industry, and the consolidation of industrial facilities to improve operational efficiency. Although these measures require substantial investment and longer implementation periods, they offer more sustainable and effective solutions for addressing the country's energy imbalance and strengthening long-term energy security (Energy Outlook Assessment [EOA], 2023; International Gas Union [IGU], 2022; Planning and Budget Organization of Iran, 2023).

8.4. Priority Policy Recommendations

Based on the findings of this study, the following five measures are identified as the highest-priority strategies for energy-intensive mineral industries:

- Establishing a gas allocation prioritization system based on industrial value added and energy efficiency performance;
- Expanding the use of renewable energy sources, particularly solar and wind power plants located in proximity to industrial facilities;
- Conducting comprehensive energy audits and developing energy efficiency benchmarks for energy-intensive industries;
- Promoting energy self-sufficiency through industrial participation in the development of oil and gas fields; and
- Gradually reforming the energy pricing system and developing an energy-saving certificate market to strengthen incentives for energy-efficiency investments.

Overall, international experience demonstrates that addressing energy imbalances cannot be achieved solely through increasing energy production. Success in this area requires a comprehensive approach that combines supply expansion, demand-side management, pricing reform, and improvements in energy efficiency. Therefore, the simultaneous implementation of these measures can provide a more sustainable pathway for securing energy supply in energy-intensive mineral industries and mitigating the adverse impacts of natural gas imbalances on the national economy (Ministry of Petroleum, Vice Presidency for

Planning, n.d.; National Productivity Organization of Iran, 2023; Parliament Research Center of the Islamic Republic of Iran, n.d.; Planning and Budget Organization of Iran, 2023).

9. Conclusion

The findings of this study indicate that the current natural gas pricing structure in Iran faces several challenges in terms of economic efficiency, investment sustainability, and the competitiveness of energy-intensive industries. The linkage of industrial feedstock and fuel prices to a pricing formula that is partially based on European gas hubs has resulted in geopolitical fluctuations beyond the control of the Iranian economy directly affecting industrial energy costs. This issue became particularly evident following the Russia–Ukraine conflict, during which natural gas prices for Iranian industries exceeded gas prices in certain North American production hubs.

Furthermore, an examination of the country's gas tariff structure reveals that the relationship between fuel prices for different industries and petrochemical feedstock prices lacks a transparent economic rationale. The existing coefficients have largely evolved over time under the influence of fiscal considerations and negotiations among stakeholders rather than being based on criteria such as value added, energy intensity, productivity, or international competitiveness. Consequently, the current structure fails to provide effective price signals for improving energy efficiency and achieving an optimal allocation of resources.

Unlike previous studies that have primarily examined gas imbalance as an energy-sector issue, this research demonstrates that natural gas imbalance in Iran is fundamentally an industrial and trade policy challenge that directly affects the competitive advantage of energy-intensive industries, non-oil exports, and the country's industrial development trajectory. To evaluate potential reform options, three alternative scenarios for revising the natural gas pricing formula were assessed. The results indicate that eliminating European gas hubs from the pricing formula would have the greatest impact on reducing the average feedstock price, lowering it from approximately 12.6 cents to 9.6 cents per cubic meter. However, such an approach could lead to a substantial reduction in government revenues and increase the formula's dependence on North American market conditions.

The scenario based exclusively on the Henry Hub benchmark also reduces the average gas price to approximately 11.7 cents per cubic meter by eliminating distortions associated with infrastructure constraints and excess supply in the Alberta market. Although this approach offers advantages in terms of simplicity and transparency, it remains vulnerable to fluctuations in international gas markets.

In contrast, the scenario involving the application of a price cap linked to Henry Hub preserves the existing pricing structure while limiting excessive price volatility. The findings suggest that imposing a cap equivalent to 1.5 times the Henry Hub price maintains the average feedstock price at a level close to the current situation while preventing severe price shocks arising from geopolitical crises. Therefore, this scenario appears to provide the most balanced solution in terms of safeguarding government revenues, preserving industrial competitiveness, and maintaining a stable investment environment. Based on the findings of this study, reforming Iran's natural gas pricing system should be guided by the following principles:

- Enhancing transparency in determining fuel prices for different industries and replacing existing coefficients with indicators based on value added, energy intensity, and productivity.
- Reducing the sensitivity of the pricing formula to external geopolitical shocks through the introduction of price ceilings and floors or by revising the weighting of benchmark gas hubs.
- Establishing a stronger linkage between pricing and energy supply security, whereby industries paying higher prices receive a greater degree of assurance regarding gas supply during peak-demand periods.
- Developing incentive mechanisms to improve energy efficiency and allocating a portion of revenues generated from pricing reforms to energy-efficiency projects in energy-intensive industries.
- Adopting pricing methodologies based on the economic value of final products, such as the Netback approach, as an alternative to the direct linkage between industrial fuel prices and petrochemical feedstock prices.

Overall, the results of this study suggest that reforming the natural gas pricing formula should simultaneously pursue three key objectives: ensuring the sustainability of government revenues, preserving industrial competitiveness, and creating incentives for improving energy efficiency. Within this framework, implementing a Henry Hub–based price cap in conjunction with revising the mechanism for determining fuel prices in mineral-based industries may serve as a balanced and practical option for the gradual reform of Iran's natural gas pricing system.

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Examining the Deficiencies of Iran's Mining Supervision System and Proposing Reform Measures Based on Comparative Studies

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Abstract

The mining sector, as a major driver of economic development, plays a crucial role in supplying raw materials, creating employment opportunities, fostering regional development, and generating economic value added. Given the non-renewable nature of mineral resources and their status as public assets and national wealth, the establishment of an effective supervisory system for mining activities is essential. This study aims to identify and assess the shortcomings of Iran's mining supervisory system and to propose appropriate reform measures. The research employs a qualitative approach based on document analysis, a review of relevant laws and regulations, an examination of existing supervisory structures, and a comparative analysis of mining oversight systems in Australia, China, and the United States. The findings reveal that Iran's mining supervision framework faces several challenges, including the multiplicity of responsible institutions, overlapping mandates, limited human and financial resources, inadequate information infrastructure, ineffective field inspection practices, and insufficient use of emerging technologies. The comparative analysis indicates that effective supervisory systems are characterized by clearly defined responsibilities, risk-based oversight, standardized inspection procedures, data-driven management systems, rigorous qualification assessments, balanced incentive and enforcement mechanisms, and sustainable resource allocation for regulatory bodies. Accordingly, this study recommends clarifying supervisory responsibilities, developing integrated mining information systems, establishing a risk-based inspection framework, strengthening institutional technical capacity, expanding the use of advanced monitoring technologies, and enhancing enforcement mechanisms. Implementing these reforms could improve governance, transparency, safety standards, environmental protection, and the sustainable exploitation of the country's mineral resources.

Keywords: Mining Governance, Risk-Based Inspection, Mine Safety, Environmental Protection

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چکیده

بخش معدن به مثابه پیشران توسعه اقتصادی، نقشی محوری در تأمین مواد اولیه، اشتغال‌زایی، توسعه منطقه‌ای و خلق ارزش‌افزوده دارد. با توجه به تجدیدناپذیری ذخایر معدنی و ماهیت آن‌ها به‌عنوان انفال و ثروت ملی، استقرار نظام نظارتی کارآمد ضرورتی انکارناپذیر است. پژوهش حاضر با رویکرد کیفی، مبتنی بر تحلیل اسناد و قوانین و مطالعه تطبیقی نظام نظارت معدنی در کشورهای استرالیا، چین و آمریکا، به آسیب‌شناسی سیستم نظارت بر معادن ایران و ارائه راهکارهای اصلاحی می‌پردازد. یافته‌ها نشان می‌دهد چارچوب نظارتی کشور با چالش‌هایی بنیادین از جمله تعدد نهادهای متولی، تداخل وظایف، تنگنای منابع مالی و انسانی، ضعف زیرساخت‌های اطلاعاتی، ناکارآمدی بازرسی‌های میدانی و عدم بهره‌گیری از فناوری‌های نوین مواجه است. در مقابل، تحلیل تطبیقی بیانگر آن است که نظام‌های نظارتی پیشرو بر تفکیک شفاف مسئولیت‌ها، نظارت مبتنی بر ریسک، استانداردسازی بازرسی‌ها، حاکمیت داده‌ها، ارزیابی دقیق صلاحیت‌ها و سازوکارهای متوازن تنبیهی تشویقی استوارند. بر این اساس، اصلاحاتی چون شفاف‌سازی وظایف حاکمیتی، ایجاد سامانه‌های یکپارچه اطلاعاتی، استقرار نظام بازرسی ریسک‌محور، ارتقای ظرفیت فنی و به‌کارگیری فناوری‌های هوشمند پایش پیشنهاد می‌شود. تحقق این اصلاحات می‌تواند حکمرانی، شفافیت، ایمنی، حفاظت از محیط‌زیست و صیانت از بهره‌برداری پایدار از ثروت‌های معدنی کشور را به میزان چشمگیری ارتقا بخشد.

1. Introduction

The mining and mineral industries sector constitutes one of the fundamental pillars of economic development in many countries around the world. It plays a significant role in supplying raw materials for various industries, generating employment opportunities, developing infrastructure, increasing foreign exchange earnings, and fostering economic growth. In countries endowed with abundant mineral resources, this sector not only satisfies domestic demands but also serves as a strategic advantage for participation in international markets and for enhancing economic competitiveness. Iran, owing to its considerable diversity of mineral resources and its position among countries possessing valuable mineral reserves, has substantial potential for the development of mining activities and related industries. This potential can contribute significantly to reducing the economy's dependence on oil revenues, promoting the development of less-developed regions, and increasing value added throughout the production chain)Islamic Republic of Iran, 1998(.

Mineral resources, under the Iranian legal framework, are regarded as public wealth, and their exploitation should be undertaken in a manner that serves the public interest and advances the country's sustainable development. Given the non-renewable nature of mineral reserves, the proper management of these resources is of critical importance. Unsound exploitation practices, excessive extraction, the wastage of mineral reserves, non-compliance with technical and environmental requirements, as well as the absence of effective oversight, may reduce the economic benefits derived from these resources and impose irreversible costs on future generations. Therefore, maximizing the economic value of mineral reserves necessitates the establishment of an efficient system for planning, management, and supervision across all stages of mining activities, from exploration and extraction to mine closure and the rehabilitation of mining sites Islamic Republic of Iran, 1998).

Supervision of mining activities constitutes one of the most important governance instruments within the mining sector. The objective of such supervision extends beyond merely monitoring the performance of mining operators; it also encompasses ensuring the sustainable and responsible exploitation of mineral reserves, safeguarding workers' health and safety, protecting the environment, preventing the infringement of the rights of the government and local communities, and enhancing transparency and accountability within the sector. Effective supervision can contribute to the accurate identification of mineral potential, verification of the reliability of exploration outcomes, monitoring of extraction volumes, reduction of mining accidents and human casualties, prevention of environmental degradation, and the proper collection of government royalties and related revenues. Conversely, weaknesses in the supervisory system may facilitate the provision of inaccurate information, lead to technical and financial violations, reduce operational efficiency, increase environmental damage, and ultimately undermine public trust in the management of the country's mineral resources (Zeinolinejad Ferdowsieh et al., 2023).

The importance of supervising mining activities is not confined to Iran; in many resource-rich countries, particularly developing nations, it constitutes one of the principal challenges of mining sector governance. International experiences indicate that factors such as shortages of skilled human resources, financial constraints, inadequate information infrastructure, a lack of transparency in contracts and performance reporting, conflicts between economic objectives and safety and environmental requirements, as well as the fragmentation of supervisory responsibilities, are among the most significant barriers to the establishment of effective regulatory systems. In response to these challenges, many countries have sought to enhance the efficiency and effectiveness of mining supervision through the adoption of emerging technologies, the development of integrated information systems, the promotion of data transparency, the strengthening of independent regulatory institutions, and the formulation of comprehensive supervisory standards (Smith & Rosenblum, 2011).

In Iran, the expansion of mining activities and the increasing number of active mines in recent years have further highlighted the need to reconsider and reform existing supervisory mechanisms. The current framework for overseeing mining activities is distributed among several governmental and professional bodies, including the Ministry of Industry, Mine and Trade, the Iranian Mining Engineering Organization, the Ministry of Cooperatives, Labour and Social Welfare, the Department of Environment, and the Forests, Rangelands and Watershed Management Organization. Each of these institutions is responsible for specific functions related to licensing procedures, supervision of mining operations, occupational safety and health, and environmental protection. Nevertheless, existing studies and assessments indicate that Iran's mining supervisory system faces a number of significant challenges, including the multiplicity of responsible institutions, overlapping or ambiguous mandates, limitations in human and financial resources, weaknesses in field inspection practices, the absence of comprehensive and integrated guidelines, insufficient utilization of emerging technologies, and the existence of certain institutional and operational conflicts. In some instances, these challenges have diminished the effectiveness of supervisory processes and hindered the achievement of their intended objectives (Islamic Republic of Iran, 2013).

Furthermore, an assessment of the current situation indicates that supervisory mechanisms in the areas of mining safety, environmental protection, and technical mining operations are confronted with several shortcomings. The occurrence of mining accidents, deficiencies in the continuous monitoring of environmental impacts, the considerable reliance on operators' self-reporting of production data, and the limited scope of field inspections are among the issues that underscore the necessity for reform and improvement of the existing supervisory system. At the same time, the advancement of emerging technologies, such as intelligent monitoring systems, satellite imagery, unmanned aerial vehicles (UAVs), and integrated information systems, has created new opportunities to enhance the accuracy, transparency, and efficiency of mining supervision. The effective adoption of these technologies could help address some of the existing challenges and strengthen the overall effectiveness of regulatory oversight in the mining sector (Babak et al., 2021; Smith & Rosenblum, 2011).

Given the strategic importance of the mining sector and the critical role of supervision in ensuring the sustainable exploitation of mineral resources, the present study aims to examine and diagnose the deficiencies of the supervisory system governing mining activities in Iran and to propose appropriate reform measures. To this end, the existing supervisory processes related to various aspects of mining activities are first analyzed, and the major challenges and regulatory bottlenecks are identified. Subsequently, through a comparative examination of the experiences of selected mining countries and an analysis of the approaches and instruments employed within their supervisory frameworks, potential capacities and best practices applicable to the enhancement of Iran's mining supervisory system are identified. Finally, based on the findings of these investigations, a set of policy and operational recommendations is proposed to improve the structure and processes of mining supervision in Iran. It is expected that the findings of this study will contribute to strengthening governance in the mining sector, enhancing transparency, improving safety and environmental protection, safeguarding mineral reserves, and increasing the efficiency of the country's mineral resource management system.

2. The Process of Supervising Mining Activities

The processes for supervising various aspects of mining activities in Australia, China, and the United States have been examined and analyzed in this study.

2.1. Mining Regulatory Oversight Processes in Australia

Australia is one of the world's largest mining countries and is widely recognized as having one of the most advanced systems of mining governance. Owing to its vast mineral reserves, particularly in iron ore, gold, bauxite, and lithium, the country has established a well-structured framework for the management and supervision of mining activities. Within Australia's governance system, although the primary responsibility for the administration and regulation of mining operations rests with state governments, federal laws and policies play a complementary role in areas such as environmental protection, occupational safety, and sustainable development. Consequently, Australia's mining supervisory system represents an example of effective interaction among specialized institutions, executive agencies, and legal mechanisms. The process of granting mining licenses is managed by the relevant state mining authorities, including departments responsible for mines and petroleum resources. Various governmental bodies are involved in the regulation and supervision of mining activities in Australia, among which the Department of Mines and Petroleum holds a particularly significant role. In Western Australia, agencies associated with the mining sector operate under the umbrella of the Department of Energy, Mines, Industry Regulation and Safety (DEMIRS). The organizational structure of these entities is illustrated in Figure 1 (Government of Western Australia, 1988).

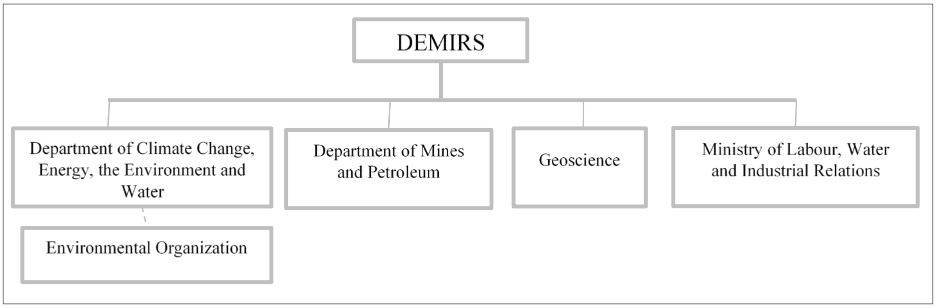

Figure 1. Relevant Organizations Involved in the Mining Sector in Australia

In Australia, the issuance of mining licenses is based on the simultaneous assessment of applicants' technical competence, financial capacity, and the environmental implications of proposed mining projects. Applicants seeking exploration and mining permits are required to submit comprehensive operational plans outlining project objectives, implementation methods, schedules, projected costs, technical capabilities, and the financial resources necessary for carrying out the proposed activities. These plans are evaluated by the relevant specialized authorities, particularly mining departments and environmental agencies, and licenses are granted only when the applicant's qualifications have been verified and the proposed project is found to comply with applicable technical and environmental requirements. One of the distinguishing features of Australia's mining supervisory system is the strong emphasis placed on the quality of technical information and the reliability of exploration and mining data. Exploration and production reports must be prepared by appropriately qualified professionals and compiled in accordance with internationally recognized standards, including the Joint Ore Reserves Committee (JORC) Code. In addition, mining operators are required to submit periodic reports detailing the progress of operations, production volumes, exploration outcomes, and the status of mineral reserves. These reports are reviewed by government experts, and any discrepancies or deficiencies identified in the submitted information must be rectified. Oversight of mining operations in Australia is primarily undertaken by government inspectors appointed and funded by the competent regulatory authorities. These inspectors conduct field inspections, review documentation, and evaluate operators' performance at specified intervals and in accordance with the risk profile of mining activities. The selection of mines for inspection is based on criteria such as the level of operational risk, the history of non-compliance, environmental sensitivity, the type of mineral being extracted, and the period elapsed since the previous inspection. This risk-based approach enables supervisory resources to be directed toward mining operations where the likelihood of violations or accidents is greater (DMIRS, 2024; Government of Western Australia, 1988).

In the area of mine safety, Australia has adopted a relatively stringent regulatory framework. All mining projects are subject to safety risk assessments prior to commencement, and mining operators are required to develop and implement risk management plans, emergency response procedures, and measures aimed at protecting the health and safety of the workforce. Safety inspections are conducted on a regular basis and in proportion to the level of risk associated with each mining operation. Safety violations are classified according to their severity, and corresponding enforcement measures have been established for each category of non-compliance. These measures include financial penalties and, in cases involving serious breaches, criminal sanctions. This regulatory approach has contributed to making compliance with safety requirements one of the principal priorities of mining companies operating in Australia (Government of Western Australia, 2022).

In the environmental domain, Australia's supervisory system is founded upon both ex ante environmental assessment and continuous monitoring. All mining projects are required to undergo environmental impact assessments prior to the commencement of operations and, where significant environmental risks are identified, must obtain the necessary environmental approvals and permits. Throughout the operational life of a mine, periodic inspections are conducted to monitor environmental impacts, oversee waste management practices, protect water resources, and minimize pollutant emissions. Furthermore, mining operators are obligated to provide financial assurance for the rehabilitation and restoration of mining sites. In this regard, the Mining Rehabilitation Fund (MRF) was established to ensure the implementation of mine closure and post-mining rehabilitation programs. Mining companies are required to make prescribed contributions to this fund, thereby providing a financial mechanism to support the restoration of disturbed areas following the cessation of mining activities (Australian Government, 1999).

Another notable feature of Australia's mining supervisory system is its emphasis on information transparency and the simultaneous use of both incentive-based and enforcement mechanisms. Alongside substantial penalties for the submission of inaccurate information, safety violations, and environmental damage, various incentives are also provided to encourage compliance among law-abiding mining operators. The public disclosure of selected mining-related information, the utilization of integrated information systems, and mandatory periodic reporting requirements further contribute to enhancing accountability and improving the overall quality of regulatory oversight. In general, Australia's system for supervising mining activities is founded upon four fundamental principles: first, the rigorous assessment of applicants' qualifications prior to the issuance of mining licenses; second continuous, risk-based supervision throughout the lifecycle of mining operations; third, the relative independence of inspection authorities from mining operators; and fourth, the use of transparent reporting and accountability mechanisms. Collectively, these characteristics have enabled Australia to emerge as one of the most successful international models of mining governance and regulatory oversight (Smith & Rosenblum, 2011).

2.2. The Process of Supervising Mining Activities in China

China's system for the management and supervision of mining activities is founded upon the Mineral Resources Law of the People's Republic of China. This law was enacted in 1986 by the Standing Committee of the National People's Congress and was subsequently amended in 1996 and 2009. In addition to this legislation, a series of implementing regulations and administrative directives issued by the State Council and other relevant executive authorities further complement the legal framework governing mineral exploration and mining operations (National People's Congress of the People's Republic of China, 2009).

Supervision of the mining sector in China is carried out through the coordinated efforts of several governmental institutions. The Ministry of Natural Resources, as the principal authority responsible for mineral resource management, oversees the registration and administration of mineral rights, the issuance of exploration and mining licenses, the supervision of extraction activities, and the sustainable management of mineral resources. The Ministry of Ecology and Environment is responsible for assessing and monitoring the environmental impacts of mining activities and collaborates with the Ministry of Natural Resources in the review and approval of mining projects. In addition, the Ministry of Emergency Management and the National Mine Safety Administration are responsible for formulating safety standards, conducting mine inspections, and overseeing compliance with safety requirements. The Ministry of Commerce also performs functions related to the trade and export of mineral products (National People's Congress of the People's Republic of China, 2009; International Comparative Legal Guides, 2025).

China's mining supervisory system is founded upon four principal pillars: the issuance of mining licenses, the supervision of exploration and extraction activities, oversight of mine safety, and monitoring compliance with environmental requirements. Within this framework, applicants seeking to engage in mining activities are required to submit technical, financial, environmental, and safety documentation, and the necessary permits are granted only after the completion of evaluation procedures and the receipt of the requisite legal approvals. Furthermore, throughout the operational life of a mine, periodic inspections, continuous reporting obligations, and the use of electronic monitoring systems are employed to ensure compliance with applicable legal and technical requirements. Overall, China's mining supervisory system is characterized by a centralized, multi-sectoral, and continuously monitored approach, in which resource management, environmental protection, workforce safety, and the sustainable exploitation of mineral reserves are addressed simultaneously (National People's Congress of the People's Republic of China, 2009;

2.3. The Process of Supervising Mining Activities in the United States

Supervision of mining activities in the United States is carried out through a combination of federal and state institutions, each of which is entrusted with specific responsibilities relating to licensing procedures, environmental protection, occupational health and safety, oversight of mining operations, and the collection of mineral-related revenues. The principal federal agencies involved in the governance and regulation of the mining sector include the Department of the Interior, the Environmental Protection Agency (EPA), the Department of Labor, and the Department of Agriculture. Figure 2 illustrates the major governmental institutions involved in the governance and supervision of the mining sector in the United States (Clawson, 1979; McAteer, 1995; U.S. Environmental Protection Agency [EPA], 1997).

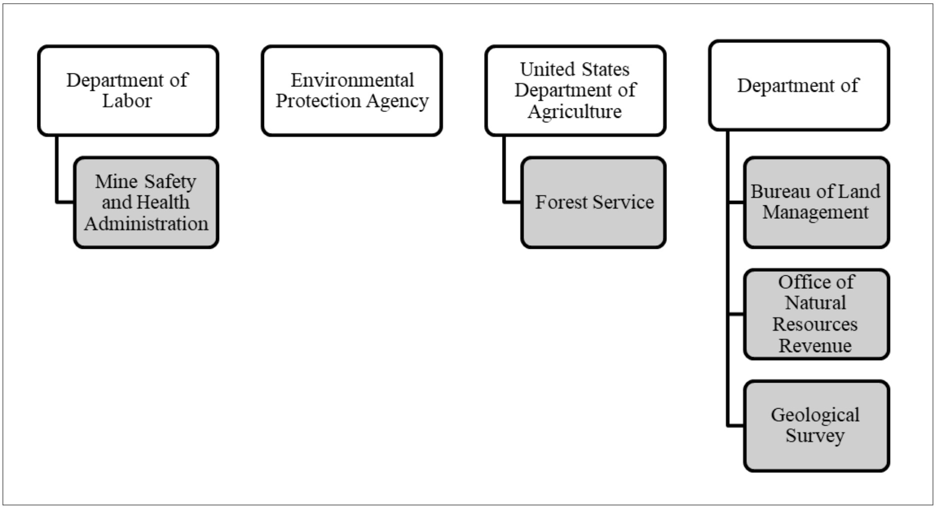

Figure 2. Relevant Organizations Involved in the Mining Sector in the United States

The Department of the Interior is the principal federal authority responsible for the management of mining activities in the United States. It exercises its regulatory and supervisory functions through several subordinate agencies, including the Bureau of Land Management (BLM), the Office of Natural Resources Revenue (ONRR), and the United States Geological Survey (USGS). The Bureau of Land Management is responsible for issuing exploration and mining permits on federal lands, reviewing operational plans, conducting periodic inspections, and overseeing compliance with environmental requirements and mine reclamation obligations. The Office of Natural Resources Revenue is charged with supervising the collection of government revenues derived from mineral extraction, including royalties and other mineral-related payments, as well as verifying the accuracy of production reports submitted by mining operators. In addition to compiling national mineral statistics and information, the United States Geological Survey provides the specialized geological and mineral data required to support the activities of regulatory and supervisory authorities (Clawson, 1979; McAteer, 1995; U.S. Environmental Protection Agency [EPA], 1997).

In the environmental domain, the EPA is responsible for overseeing the implementation and enforcement of federal legislation, including the Clean Air Act, the Clean Water Act, and other environmental regulations applicable to mining activities. Through the monitoring of pollutant emissions, the assessment of environmental impacts, and the imposition of regulatory control measures, the EPA seeks to minimize the adverse environmental consequences of mining operations. In addition, the Department of Labor, through the Mine Safety and Health Administration (MSHA), is responsible for establishing and enforcing mine safety standards, conducting periodic inspections, and investigating mining accidents. Through these functions, MSHA plays a central role in safeguarding the health and safety of mine workers and ensuring compliance with occupational safety requirements across the mining sector (U.S. Environmental Protection Agency [EPA], 1997; Mine Safety and Health Administration [MSHA], 2020; U.S. Environmental Protection Agency [EPA], n.d).

The process of issuing mining permits on federal lands is primarily administered by the BLM. Applicants are required to submit technical and operational information relating to the proposed project, including exploration or extraction plans, environmental assessments, and land reclamation plans. For projects located within National Forest System lands, the United States Forest Service (USFS) also participates in the review and approval of proposed mining plans. Pursuant to the National Environmental Policy Act (NEPA), many mining projects must undergo environmental impact assessment procedures prior to permit issuance, and in certain cases, opportunities for public participation and comment are incorporated into the decision-making process. Following the issuance of permits, oversight of mining operations is carried out through field inspections, reviews of technical and financial reports, monitoring of the implementation of reclamation plans, and the assessment of environmental performance indicators. Mining operators are required to provide the competent authorities with information concerning production volumes, operational status, environmental management measures, and reclamation activities. Regulatory agencies, in turn, evaluate the accuracy and reliability of the submitted information through on-site inspections, integrated information systems, remote sensing technologies, and satellite imagery (U.S. Environmental Protection Agency [EPA], 1997; USDA Forest Service, 2012).

The system for supervising mineral production in the United States is founded upon the principles of continuous reporting by mining operators and the cross-verification of production and financial data. The BLM and the ONRR oversee extraction activities and the collection of government revenues through the review of production reports, the conduct of financial audits, and the reconciliation of operational and financial records. These mechanisms are intended to ensure the accuracy of reported production volumes and compliance with royalty payment obligations. In addition, the USGS plays a significant supporting role in the country's regulatory framework by compiling and disseminating official statistics on mineral production and reserves. The availability of reliable and comprehensive mineral data enhances transparency, facilitates evidence-based decision-making, and provides essential informational support for regulatory and supervisory authorities responsible for the governance of the mining sector (Office of Natural Resources Revenue [ONRR], 2020; U.S. Geological Survey [USGS], 2023)

The mine supervision system in the United States is characterized by a multi-layered and specialized structure, within which responsibilities related to safety, occupational health, and environmental protection are distributed among various federal agencies. In the area of mine safety and miners' health, the MSHA bears primary responsibility for establishing and enforcing safety standards, conducting inspections, investigating mining accidents, and implementing enforcement measures. In the environmental domain, the EPA, in conjunction with agencies such as the BLM and the USFS, oversees compliance with environmental requirements and the protection of natural resources associated with mining activities. Through this institutional arrangement, the United States seeks to balance mineral resource development with the protection of workers' health and safety and the conservation of environmental values (U.S. Environmental Protection Agency [EPA], 1997; USDA Forest Service, 2012).

One of the distinguishing features of the United States' mining supervisory system is its risk-based approach to the planning and implementation of inspections. Although legislation prescribes a minimum number of annual inspections for mining operations, factors such as the history of regulatory violations, the level of operational hazards, geological conditions, the presence of hazardous substances, and registered complaints also play a significant role in determining inspection priorities. This approach enables supervisory resources to be strategically directed toward high-risk mines and operations with a history of non-compliance. Another notable strength of this system is the use of performance assessment mechanisms such as the Significant and Substantial (S&S) designation and the Pattern of Violations (POV) framework. These instruments facilitate the identification of serious violations and the detection of recurring patterns of regulatory non-compliance, thereby providing a basis for the intensification of supervisory and enforcement actions in high-risk mining operations. Furthermore, the public disclosure of selected inspection findings and regulatory violations contributes to greater transparency in the oversight process and enhances the accountability of mining operators (McAteer, 1995; Office of Natural Resources Revenue [ONRR], 2020; MSHA, 2024).

In the environmental domain, the United States' regulatory oversight system is based on a comprehensive and coordinated body of federal legislation that encompasses all stages of the mining life cycle, from exploration and extraction to mine closure and reclamation. Mandatory environmental assessments, the control of water and air pollution, the management of mining waste, the protection of sensitive species, and the rehabilitation of disturbed lands following the cessation of mining activities constitute some of the principal components of this framework. Furthermore, mining operators are required to provide adequate financial assurances to guarantee the implementation of reclamation programs and to cover potential environmental liabilities arising from mining operations. These financial mechanisms are intended to ensure that the costs associated with environmental restoration and remediation are borne by the responsible parties rather than transferred to the public sector (U.S. Environmental Protection Agency [EPA], 1997; United States Congress, 1970)

Overall, the experience of the United States demonstrates that the establishment of an effective supervisory system in the mining sector requires the existence of clear and comprehensive legislation, independent and specialized regulatory institutions, continuous and risk-based inspections, effective enforcement mechanisms, information transparency, and coordination among responsible agencies. These components, together with ongoing training initiatives and the active participation of mining operators, play a significant role in reducing mining accidents, enhancing safety performance, and strengthening environmental protection. As such, they may serve as valuable lessons for the reform and development of mining supervisory systems in other countries. In summary, the United States' mining supervisory framework is characterized by the distribution of responsibilities among specialized institutions, the extensive use of environmental assessment tools, periodic inspections, continuous reporting systems, and the application of advanced monitoring technologies. This structure enables the simultaneous oversight of the technical, economic, safety, and environmental dimensions of mining activities, thereby contributing to a more integrated and effective system of mining governance McAteer, 1995; U.S. Environmental Protection Agency [EPA], 1997; IWG, 2023)

3. Summary of Comparative Study Findings and Their Implications for the Mine Supervision System in Iran

An examination of the supervisory frameworks governing mining activities in the countries under study reveals that, despite differences in their legal and administrative systems, certain common principles exist across all of them that play a decisive role in enhancing the effectiveness of mining oversight. The most significant finding of this comparative analysis is that the success of mining supervisory systems depends less on the number of regulatory institutions involved and more on the clarity of institutional responsibilities, the accountability of competent authorities, the existence of well-defined standards, the provision of adequate financial resources, and the adoption of data-driven regulatory approaches (Zeinolinejad Ferdowsieh et al., 2023; Babak et al., 2021).

he first major finding of this study concerns the clear delineation of supervisory responsibilities among different regulatory bodies. In the countries examined, mine safety, environmental protection, and oversight of technical mining operations are generally entrusted to independent specialized institutions. For example, in the United States, the MSHA bears direct responsibility for supervising the safety and health of mine workers, while the EPA and other specialized agencies oversee environmental matters and land-use aspects associated with mining activities. This division of responsibilities has contributed to enhanced accountability, greater specialization, and a reduction in institutional overlap. In contrast, an examination of the current situation in Iran indicates that the fragmentation of responsibilities and the absence of a clearly identifiable accountable authority constitute some of the most significant factors undermining the effectiveness of the country's mining supervisory system (Zeinolinejad Ferdowsieh et al., 2023; Babak et al., 2021; U.S. Environmental Protection Agency [EPA], 1997).

The second major finding concerns the existence of comprehensive systems of standard-setting and inspection. In the countries examined, inspections are conducted in accordance with integrated guidelines, predefined indicators, and clearly established procedures. Inspectors are required to document all stages of the inspection process based on approved standards, and the resulting findings serve as the basis for subsequent enforcement actions. In many cases, the severity of violations, the compliance history of mining operators, and the risk level associated with individual mining operations are assessed through established evaluation frameworks and dedicated monitoring systems. These observations suggest that effective oversight depends upon the existence of standardized, measurable, and verifiable criteria that can provide a reliable foundation for regulatory decision-making and enforcement (Zeinolinejad Ferdowsieh et al., 2023; Babak et al., 2021; Mine Safety and Health Administration [MSHA], 2020)

The third major finding of this study highlights the importance of adopting a risk-based approach to inspection planning. Unlike traditional practices, in which all mining operations are inspected according to a uniform model, the countries examined employ risk-based prioritization systems to allocate supervisory resources more effectively. In these jurisdictions, factors such as the history of regulatory violations, the type of mineral extracted, mining methods, the level of safety hazards, environmental sensitivities, and records of previous accidents play a fundamental role in determining the frequency, scope, and nature of inspections. This approach ensures that limited regulatory resources are directed toward mining operations that present the highest likelihood of adverse events and regulatory non-compliance. Consequently, risk-based oversight enhances the efficiency and effectiveness of supervisory activities by enabling regulatory authorities to focus their attention on areas of greatest concern (Smith & Rosenblum, 2011).

The fourth major finding of this study concerns the pivotal role of information systems and data-driven approaches in the oversight process. In leading mining jurisdictions, a substantial proportion of supervisory activities is based on the continuous collection of information, self-reporting by mining operators, centralized databases, and the cross-validation of data from multiple sources. In addition to conducting field inspections, these countries employ intelligent monitoring tools to identify deviations from approved operational plans, detect regulatory violations, and assess the performance of mining operators. In contrast, weaknesses in data infrastructure and the lack of information integration in Iran have limited the capacity of regulatory authorities to verify the accuracy and reliability of information submitted by mining operators. As a result, deficiencies in data management and interoperability constitute significant obstacles to the development of a more effective and evidence-based mining supervisory system (Zeinolinejad Ferdowsieh et al., 2023; Smith & Rosenblum, 2011).

The fifth major finding highlights the importance accorded to the technical and financial qualifications of applicants seeking to engage in mining activities. In the countries examined, the assessment of applicants is not based solely on individual characteristics or formal eligibility requirements; rather, it encompasses a comprehensive evaluation of their capacity to implement the proposed mining project, their financial capability, the competence of their technical team, and the adequacy of their safety and environmental management plans. This approach ensures that only those applicants possessing the necessary resources, expertise, and organizational capacity are granted access to mining activities. Consequently, it promotes the responsible, safe, and sustainable execution of mining operations while reducing the likelihood of technical failures, safety incidents, and environmental non-compliance arising from inadequate operator capacity (Smith & Rosenblum, 2011; USDA Forest Service, 2012).

The sixth major finding of this study concerns the existence of deterrent penalty systems coupled with incentive mechanisms designed to enhance mine performance. In most of the countries examined, serious violations may result in substantial financial penalties, suspension of operations, revocation or suspension of licenses, or the intensification of regulatory inspections. Conversely, mining operations that demonstrate satisfactory performance in the areas of safety, environmental management, and regulatory compliance may benefit from incentives such as reduced inspection frequency, the award of recognized certification schemes, and access to certain administrative facilitation measures. This balanced combination of punitive and incentive-based instruments has contributed to strengthening the culture of regulatory compliance within the mining sector. By simultaneously discouraging non-compliant behavior and rewarding good performance, these mechanisms encourage mining operators to adopt higher standards of operational responsibility and continuous improvement (Zeinolinejad Ferdowsieh et al., 2023; Smith & Rosenblum, 2011; International Comparative Legal Guides, 2025).

Finally, comparative studies indicate that effective mining supervision requires regulatory authorities to have access to stable financial resources, specialized human capital, and sufficient institutional independence in the execution of their mandates. In all the countries examined, a significant portion of supervisory costs is financed by the government, and regulatory agencies rely on trained and qualified professional staff. Accordingly, any reform of the mining supervisory system in Iran should not be limited to legal and structural adjustments alone; rather, it must also address the provision of sustainable financing mechanisms and the development of the technical and professional capacities of supervisory institutions (Zeinolinejad Ferdowsieh et al., 2023; Smith & Rosenblum, 2011; Babak et al., 2021).

Based on the above findings, the proposed recommendations are designed to achieve five main objectives, namely: clarifying supervisory responsibilities, enhancing the accountability of responsible agencies, establishing a risk-based supervisory system, developing data-driven oversight mechanisms, and strengthening enforcement measures.

4. Conclusion

The mining sector, due to its strategic role in economic development, the supply of industrial raw materials, and the generation of added value, requires an efficient and effective system for the management and supervision of mining activities. Given that mineral resources are considered both public assets and non-renewable national wealth, their sustainable and responsible exploitation necessitates the establishment of precise, transparent, and accountable regulatory mechanisms across all stages of mining, including exploration, extraction, and mine rehabilitation.

An examination of the current state of the mining supervisory system in Iran indicates that, despite the existence of a legal framework and the involvement of multiple responsible institutions, the system faces several challenges, including the fragmentation of supervisory responsibilities, overlap of mandates, shortage of specialized human resources, limited financial capacity, weak information infrastructure, insufficient field inspections, and limited utilization of modern technologies. These challenges have led to reduced effectiveness of supervision, difficulties in verifying the accuracy of submitted information, an increased likelihood of regulatory violations, and a decline in the efficiency of mineral resource management.

The comparative study of the mining supervisory systems in Australia, China, and the United States demonstrates that the effectiveness of mining oversight depends primarily on the existence of transparent and specialized institutional structures, a clear delineation of responsibilities, the establishment of risk-based supervisory systems, the utilization of integrated information systems, the application of advanced monitoring technologies, the enforcement of effective regulatory measures, and the availability of sufficient independence and resources for regulatory authorities. Furthermore, the experience of these countries indicates that effective supervision is not limited to field inspections alone; rather, it is based on a combination of reliable data, continuous reporting, intelligent monitoring, and robust accountability mechanisms.

Accordingly, reforming the mining supervisory system in Iran requires a revision of existing structures and processes, clarification of the responsibilities of relevant authorities, development of integrated mineral information systems, establishment of a risk-based supervisory framework, strengthening the technical capacities of regulatory institutions, and expanding the use of technological tools such as intelligent monitoring systems, remote sensing, and drones. Moreover, the introduction of a balanced system of incentives and penalties, enhancement of information transparency, and provision of sustainable financial resources for supervisory functions can further improve the efficiency and effectiveness of the system.

In summary, achieving good governance in the mining sector and ensuring the sustainable exploitation of national mineral resources depends on the establishment of an integrated, data-driven, accountable, and standards-based supervisory system. Such a system, in addition to safeguarding mineral resources and public interests, can contribute to improving mine safety, strengthening environmental protection, enhancing economic transparency, and increasing public trust in the management of the country's mineral resources.

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Interpreting Production Pressures in Iranian Manufacturing Through a Multilevel Resilience Framework

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Abstract

This article interprets production-related pressures in Iranian manufacturing through a multilevel resilience framework encompassing firm-level conditions, sectoral variation, and macro-institutional constraints. Drawing on secondary data from official statistical sources and manufacturing Purchasing Managers' Index (PMI) indicators, the study adopts a descriptive and diagnostic approach rather than a causal one. The evidence indicates that recent manufacturing conditions in Iran have been characterized by rising input prices, weak raw-material inventories, liquidity constraints, foreign-exchange pressures, regulatory instability, and energy-related disruptions. Sectoral evidence further points to uneven industrial conditions, with PMI outcomes varying across industries. These differences may be associated with variation in supply-chain structure, import dependence, and exposure to infrastructural stress, although the available data do not permit direct testing of such relationships. At the macro level, the findings suggest the coexistence of fiscal pressure, short-term financing patterns, and unstable institutional and energy conditions that shape the broader environment in which industrial production takes place. Taken together, these patterns may be interpreted as more consistent with survival-oriented adjustment than with clearly demonstrated strategic resilience. The article therefore offers a conceptually informed and descriptively grounded interpretation of industrial resilience as a multilevel phenomenon, while recognizing the limits of the available evidence for establishing causal effects or cross-level interactions.

Keywords: Supply chain resilience; Institutional constraints; Post-conflict economic recovery

چکیده

این مقاله فشارهای ناظر بر تولید در بخش صنعت ایران را در قالب چارچوبی چندسطحی از «تاب‌آوری»، شامل شرایط بنگاهی، تفاوت‌های بخشی و تنگناهای نهادی-کلان تبیین می‌کند. این مطالعه با اتکا به داده‌های ثانویه آماری رسمی و شاخص مدیران خرید بخش صنعت، رویکردی توصیفی-تشخیصی را برای تحلیل وضع موجود به کار می‌گیرد. شواهد حاکی از آن است که محیط تولید صنعتی در سال‌های اخیر متأثر از جهش قیمت نهاده‌ها، تحلیل موجودی مواد اولیه، مضیقه نقدینگی، تنش‌های ارزی، بی‌ثباتی مقرراتی و ناترازی حامل‌های انرژی بوده است. در سطح بخشی، نوسانات نامتوازن شاخص نشان‌دهنده ناهمگونی عملکرد صنایع مختلف است؛ ناهمگونی‌هایی که احتمالاً از تفاوت در ساختار زنجیره تأمین، عمق وابستگی به واردات و شدت آسیب‌پذیری در برابر شوک‌های زیرساختی نشأت می‌گیرد. در سطح کلان نیز تلاقی فشارهای مالی، الگوهای تأمین مالی کوتاه‌مدت و ناپایداری‌های نهادی و انرژی، بستر فعالیت صنعتی را به‌شدت تحدید کرده است. جمع‌بندی این متغیرها نشان می‌دهد که واکنش کنونی صنعت ایران بیش از آنکه تجلی «تاب‌آوری راهبردی» باشد، بازتابی از رفتارهای انطباقیِ «بقامحور» در برابر شوک‌هاست. در نهایت، این مقاله تفسیری مفهومی و متکی بر شواهد از تاب‌آوری صنعتی به مثابه پدیده‌ای چندسطحی ارائه می‌دهد، هرچند بر محدودیت‌های داده‌ای در اثبات روابط علّی میان‌سطحی تأکید می‌ورزد.

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1. Introduction

In recent years, production resilience has gained increasing prominence in operations management, industrial policy, and crisis studies. The growing frequency of economic, political, and environmental disruptions has intensified attention to the conditions under which production systems can sustain continuity under stress. Within this literature, resilience is generally defined as the capacity to absorb disruption, adapt to shifting conditions, and maintain an acceptable level of operational continuity when faced with external shocks (Christopher & Peck, 2004; Sheffi & Rice, 2005). From this perspective, resilience is significant not only for firm performance but also for the stability of value chains and the preservation of productive capacity under uncertainty.

This article distinguishes production resilience from two related but distinct concepts: "production continuity," which refers to the maintenance of core production activities during disruption, and "strategic resilience," which denotes longer-term capacities for restructuring, renewal, and capability building beyond immediate survival. Accordingly, the continuation of production under crisis conditions should not be automatically interpreted as evidence of developed strategic resilience. In many cases, continuity may instead reflect short-term coping or survival-oriented adjustments. This distinction is particularly relevant to Iranian manufacturing, where production operates under the combined pressure of structural and recurrent disruptions, including exchange-rate volatility, regulatory instability, restricted access to imported inputs and technology, liquidity pressures, and recurring energy-related disruptions.

In such a context, the persistence of production does not necessarily indicate robust strategic adaptation; it may instead reflect constrained efforts to maintain minimum operational viability under stress. Existing research suggests that firms may reduce vulnerability through supplier diversification, strategic inventory management, and greater process flexibility. However, the effectiveness of these responses is often limited when broader supply-chain, sectoral, and institutional conditions remain unsupportive (Pettit et al., 2010). Therefore, production resilience should not be treated as an exclusively firm-level attribute. Rather, it is more appropriately understood as being conditioned by the interaction between organizational capacities and the wider environment in which production systems are embedded.

A further issue concerns the propagation of disruption across production networks. Research on resilience and supply-chain disruption indicates that shocks may extend beyond individual firms through supplier linkages, infrastructural dependencies, and institutional bottlenecks. This perspective is consistent with a multilevel understanding of production resilience, in which firm capabilities, network relations, and macro-institutional conditions jointly shape the durability of production systems. However, analytically integrated treatments of these levels in the context of Iranian manufacturing remain limited. Accordingly, this article develops a conceptual and interpretive framework for examining production-related pressures in Iranian manufacturing from a multilevel perspective. Rather than adopting either a purely firm-centered or a purely policy-centered view, this study considers how organizational conditions, sectoral variation, and institutional constraints relate to production continuity under persistent stress. The objective is to provide a structured, evidence-informed interpretation of manufacturing pressures through the lens of multilevel resilience rather than to test causal interactions directly.

This study contributes to the literature on industrial resilience in three distinct ways. First, it develops an analytically integrated framework that bridges the gap between firm-level operational realities and broader macro-institutional constraints. By synthesizing these levels, the article delineates the complex dynamics that shape industrial activity in high-uncertainty environments, moving beyond siloed analyses of either individual firm strategy or aggregate economic policy. Second, it reframes resilience not as a static, inherent outcome, but as a multilevel, context-dependent process. This perspective is particularly pertinent for understanding how firms in economies subject to structural shocks prioritize survival-oriented adjustments over long-term strategic renewal. Finally, the research provides a diagnostic tool for researchers and policymakers alike. By employing a structured interpretation of available industrial indicators, such as the Manufacturing Purchasing Managers' Index (PMI) and official statistics, this study translates fragmented descriptive data into a coherent narrative of industrial pressures. Consequently, the framework serves not as a definitive causal model, but as a robust platform for evidence-informed discourse in industrial policy, offering a nuanced lens through which to interpret production continuity in the face of persistent volatility.

2. Theoretical Foundations and Literature Review

Resilience has emerged as a central concept in the analysis of production systems operating under unstable, high-risk, and crisis-prone conditions. While initially rooted in engineering, ecology, and crisis studies (Gunderson & Holling, 2002; Hollnagel et al., 2006), the term has gained prominence in operations management, supply chain management, and industrial economics. Across these disciplines, resilience is consistently understood as a system's capacity to withstand disruption, maintain core functions, adapt to environmental shifts, and recover after a shock (Ponomarov & Holcomb, 2009; Sheffi & Rice, 2005). Given that these fields emphasize different dimensions of the phenomenon, an integrated approach, viewing production resilience as a multidimensional and multilevel construct, is essential for meaningful analysis.

In operations management, resilience is characterized by a system's ability to sustain acceptable performance levels during internal or external disturbances and to recover within a reasonable timeframe (Craighead et al., 2007; Ivanov et al., 2017). Attention is directed toward process design, capacity planning, and resource allocation to mitigate the likelihood of severe interruption. From this perspective, resilience encompasses the entire cycle of disruption: preparedness before an event, adaptive adjustment during the crisis, and the reconfiguration of resources afterward (Fiksel, 2003; Kleindorfer & Saad, 2005). A resilient firm is thus one that balances operational efficiency with responsiveness, preserving continuity through durable organizational arrangements (Chowdhury & Quaddus, 2017)

a. Resilience framework

Within the supply chain literature, resilience is framed as a networked capacity whereby firms anticipate, absorb, and contain disruptions across interconnected relationships (Christopher & Peck, 2004; Scholten & Schilder, 2015). Research in this domain emphasizes that firm-level outcomes are often inseparable from broader supply-chain conditions; disruptions frequently propagate through supplier linkages, transportation networks, and information flows (Blackhurst et al., 2005; Scheibe & Blackhurst, 2018). Consequently, resilience is viewed not merely as an intra-organizational capability, but as a relational attribute where collaboration, visibility, and flexibility serve as critical components for returning a system to a stable state (Brandon-Jones et al., 2014; Pettit et al., 2013).

In industrial economics, the concept is closely associated with the stability of production structures and the preservation of competitive capacity (Martin & Sunley, 2015; Simmie & Martin, 2010). Analysis in this field focuses on how systemic shocks, such as trade restrictions, exchange-rate volatility, and policy instability, affect cost structures, scale of production, and firm continuity (Boschma, 2015; Bristow & Healy, 2014). Resilience is often discussed in terms of survival capacity, input substitution, and the role of industrial policy in mitigating vulnerability (Aiginger, 2014; Rodrik, 2008). In contexts characterized by persistent economic pressure, research suggests that structural instability may incentivize short-term, survival-oriented responses rather than long-term strategic restructuring (Lall, 2001; Martin, 2012).

Finally, the crisis management literature highlights capacities for prevention, response, and recovery (Pearson & Clair, 1998; Roux-Dufort, 2007). In this tradition, crisis is treated as a persistent feature of the organizational environment rather than an exceptional event (Boin & van Eeten, 2013; Mitroff, 2005). Resilience is therefore linked to scenario planning, business continuity arrangements, and post-incident learning (Burnard & Bhamra, 2011; Lampel et al., 2006). A resilient organization is one that effectively limits the severity of disruption and converts crisis experience into a basis for strengthening future capabilities (Carmeli & Markman, 2011; Weick & Sutcliffe, 2007).

A synthesis of these perspectives suggests that, despite varying analytical emphases, resilience converges around four recurring dimensions: shock absorption, continuity of core performance, adaptation to changing conditions, and recovery (Bhamra et al., 2011; Hohenstein et al., 2015; Kamalahmadi & Parast, 2016). While operations management focuses on internal processes, supply chain management on network relationships, industrial economics on structural policy conditions, and crisis management on contingency and learning, these distinctions are complementary. For the purposes of this study, this convergence indicates that production resilience in an unstable economic setting is more accurately interpreted as a multidimensional, multilevel phenomenon than as a single measurable attribute (Ali et al., 2017; Pettit et al., 2010).

b. Conceptual Pillars of the Multilevel Framework

To operationalize this understanding, the analysis draws on five core concepts that recur throughout the resilience literature:

1. **Flexibility:** The ability of a system to modify resources, processes, or plans without severe deterioration in performance. This capability enables firms to move away from rigid operating patterns under uncertainty and preserve alternative pathways for production and procurement.
2. **Agility:** The capacity for rapid and effective response to environmental change. While flexibility provides the potential for change, agility emphasizes the speed of detection, decision-making, and execution, allowing for the timely mobilization of resources.
3. **Redundancy:** The existence of alternative capacities, such as safety stock, backup infrastructure, or multiple suppliers, that remain available under disruptive conditions. Durable resilience often depends on "intelligent redundancy," calibrated to the risk profile and the specific costs of failure.
4. **Business Continuity:** The structured set of plans and arrangements aimed at maintaining vital functions during crisis. By identifying critical activities and establishing recovery procedures, business continuity reduces reliance on improvised or unsystematic reactions during periods of instability.
5. **Organizational Learning:** The foundational capacity to reflect on past disruptions and adapt future practices. Resilience is not merely a matter of resistance; it requires institutional memory and iterative improvement, providing a bridge between short-term continuity and long-term strategic capability

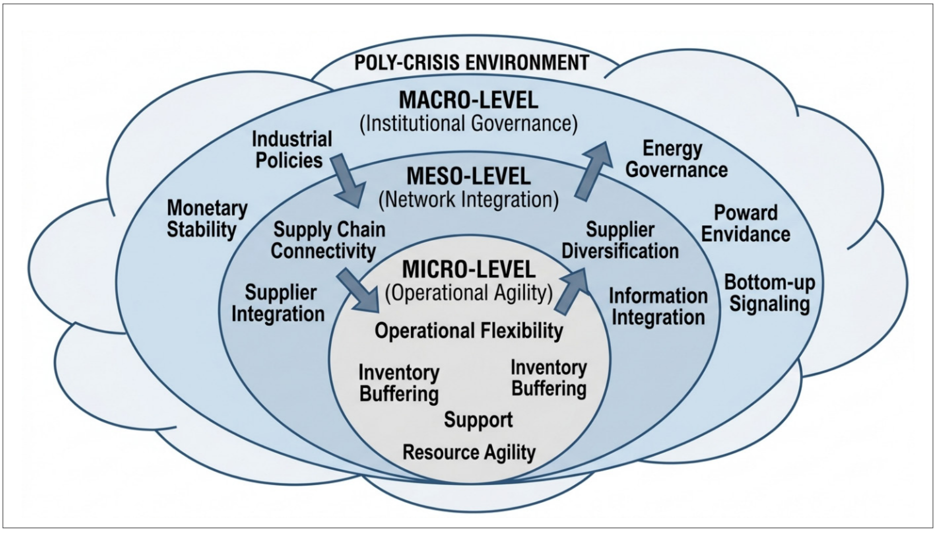

Figure [1]. Multi-level Production Resilience Model

3. Review of Domestic and International Studies

The literature on production resilience and supply chain resilience has expanded considerably across operations management, industrial policy, risk management, and crisis studies. A common thread in this body of work is the recognition that economic, political, technological, and environmental disruptions are not necessarily exceptional or temporary, but may constitute persistent features of the contemporary business environment. As a result, firms and production networks are increasingly expected to maintain continuity, adapt to disruption, and recover under conditions of uncertainty, while still facing the constraints of cost efficiency and competitiveness.

a. Foreign Literature Review

International scholarship has made a substantial contribution to the conceptualization and operationalization of supply chain resilience. Christopher and Peck (2004) were among the early scholars to present supply chain resilience as a strategic capability for dealing with disruption. Their work suggests that globally extended supply chains, especially those shaped by lean production, cost minimization, and extensive outsourcing, may be more exposed to external shocks. They argue that resilience requires the integration of risk management, inter-organizational collaboration, information visibility, and flexibility. This line of research shifted attention from resilience as a general managerial ideal toward resilience as a design principle embedded in supply chain architecture.

Sheffi and Rice (2005) further developed this perspective by examining resilience at both the firm and supply chain levels. Their work implies that organizational resilience cannot be fully understood without reference to the broader network in which the firm operates. They highlight mechanisms such as alternative sourcing, reserve capacity, operational flexibility, and collaboration with partners as important ways of reducing vulnerability to disruption. In this view, resilience is not merely a reactive response after crisis, but also a form of preparedness that may reduce the scale and duration of operational interruption.

A major contribution to this literature was made by Pettit et al. (2010), who offered one of the most widely cited frameworks for assessing supply chain resilience. Their model links resilience capabilities to vulnerabilities arising from disruption, complexity, and resource constraints. In their framework, capabilities such as flexibility, capacity, efficiency, visibility, collaboration, and adaptability may help reduce exposure to disruption or improve the ability to respond to it (Pettit et al., 2013). This contribution is particularly important because it treats resilience not only as a conceptual construct, but as a multidimensional attribute that can be assessed and managed through operational choices.

More recent studies have drawn attention to the networked nature of disruption. Habibi et al. (2023), for example, suggest that supply chain shocks may propagate across connected actors rather than remain confined to a single firm or node. Their work underscores the importance of network structure, interdependence, and transmission effects in resilience analysis (Ivanov, 2020; Scheibe & Blackhurst, 2018). This perspective is especially relevant for settings in which firms depend on a limited number of suppliers, logistics corridors, or critical inputs, since disruption in one segment may be associated with wider production instability.

Other international studies have examined the behavior of firms under sanctions, crisis conditions, and socio-economic shocks (Ahn & Ludema, 2020; Dizaji & van Bergeijk, 2013; Evenett & Fritz, 2021). Across this literature, disruption is often treated as a structural condition that may shape firm behavior, supply chain organization, and industrial strategy. Financial restrictions, trade barriers, technology access problems, and higher transaction costs are frequently discussed as factors that may erode resilience and encourage firms to rely on coping strategies such as supplier substitution, input localization, and network reconfiguration (Gereffi et al., 2022; Khorana et al., 2021). However, the effectiveness of such strategies appears to vary considerably depending on sectoral structure, institutional support, and the duration of the shock.

b. Iran-Focused Studies

In the Iranian context, Vizvбri and Shakeri (2016) provide an important reference point for understanding how sanctions affect supply chain management. Their study suggests that sanctions are associated with heightened supply-chain risk, particularly through financial instability, exchange-rate volatility, fluctuations in raw material prices, and constrained access to resources. This finding is significant because it points to the interaction of financial, commercial, and institutional constraints in shaping firm vulnerability, rather than attributing fragility to internal management inefficiencies alone.

At the firm level, Cheratian et al. (2022) examined the survival strategies of Iranian firms under sanctions. Their findings indicate that many small and medium-sized enterprises (SMEs) have relied on cost-cutting, adjustments in sales patterns, operational modifications, and informal networks to remain active. While these responses are critical for short-term survival, they do not necessarily indicate durable resilience, as they are predominantly reactive and rarely strengthen long-term production capacity or strategic competitiveness.

Sector-specific studies also provide corroborating empirical evidence. Bastani et al. (2021), for instance, examined resilience in Iran's pharmaceutical supply chain under persistent political and economic pressure. Their findings suggest that sectoral resilience can be strengthened through targeted support for domestic production, enhanced coordination among value-chain actors, modernized information systems, and institutional support. Although their analysis focused on the pharmaceutical industry, these implications readily extend to other manufacturing sectors, particularly capital goods and heavy industries, where imported intermediate inputs, regulatory coordination, and logistical stability are critical.

Recent Iranian scholarship has also addressed supply chain redesign under the compounded conditions of sanctions and external market disruptions. Nikian et al. (2022), for example, evaluated resilient and sustainable closed-loop supply chain configurations under systemic shocks. Their work demonstrates that resilience-oriented decisions are tightly bound to network redesign, multi-echelon resource allocation, and the balancing of economic viability with recovery capacity. Taken together, this stream of domestic research reinforces the core premise that production resilience in Iran cannot be reduced to isolated firm-level coping mechanisms; rather, it must be addressed as a network-wide and institutionally mediated phenomenon.

c. Synthesis and Research Gap

A defining feature of the extant empirical literature on Iranian industrial resilience is structural fragmentation. Many studies concentrate on a single manufacturing sub-sector, an isolated shock category, or a single analytical level of resilience. While these works offer granular insights into specific vulnerabilities and short-term coping mechanisms, they rarely synthesize firm-level dynamic capabilities, supply-chain network architectures, and overarching institutional constraints into an integrated framework. Consequently, the literature generates context-bound observations that remain difficult to generalize across heterogeneous industrial sectors or translate into systemic industrial policy instruments (Pettit et al., 2019; Sheffi & Rice, 2005).

To establish an integrative baseline, the literature can be categorized into three distinct analytical streams:

1. **Internal Firm Capabilities:** Studies focusing on endogenous operational parameters, including production flexibility, agile capacity planning, strategic redundancy, inventory buffering, and organizational learning (Golicic et al., 2020; Hohenstein et al., 2015).
2. **Supply Chain and Network Relations:** Studies examining inter-organizational dynamics, such as multi-tier supplier collaboration, multi-sourcing strategies,

buyer–supplier dependency, and the propagation of disruption across complex networks (Habibi et al., 2023; Scheibe & Blackhurst, 2018).

3. **Institutional and Macroeconomic Environment:** Studies addressing structural constraints, including international economic sanctions, foreign exchange volatility, capital market frictions, regulatory uncertainty, and state industrial interventions (Cheratian et al., 2022; Vizvŏri & Shakeri, 2016).

The fundamental research gap identified in this study is the marked absence of an indigenous, multilevel analytical framework that bridges these three streams within Iran's unique institutional and operational landscape. Prevailing global resilience frameworks provide robust conceptual tools, yet they were predominantly calibrated for advanced industrial economies characterized by institutional stability, deep financial markets, and highly predictable logistical corridors (Ivanov, 2020; Pettit et al., 2010). Conversely, Iran-focused studies have documented the acute pressures of geopolitical shocks and macroeconomic volatility, but have largely failed to consolidate these insights into a unified, multilevel operational model.

Accordingly, this study addresses the empirical and theoretical divide by conceptualizing production resilience in Iran as an interdependent, multilevel construct rather than an isolated managerial mandate or a purely top-down policy outcome. In operational reality, shop-floor decisions regarding safety stock, supplier contracts, and production schedules are continuously constrained by foreign-exchange allocation rules, trade barriers, and credit rationing. Conversely, state-level industrial policies that overlook operational realities and network-level interdependencies inevitably yield sub-optimal results. This article therefore proposes a context-sensitive, multilevel framework to evaluate and reinforce production resilience in Iranian manufacturing under chronic structural crisis conditions.

Table 1. Summary of Literature Review

Research Axis	Main Focus	Representative Sources	Limitations for the Present Study
Supply Chain Resilience	Flexibility, agility, collaboration, visibility, and risk management in responding to disruption	Christopher & Peck (2004); Sheffi & Rice (2005); Pettit et al. (2010)	Limited attention to sanction-related constraints and the institutional conditions of the Iranian economy
Network Disruption Propagation	Network-based transmission of disruptions and interdependencies across supply chain actors	Habibi et al. (2023)	Greater emphasis on network effects than on the policy and industrial context of Iran

Research Axis	Main Focus	Representative Sources	Limitations for the Present Study
Firms Under Sanctions	Survival strategies, vulnerability reduction, and adaptation under financial and trade constraints	Vizvári & Shakeri (2016); Cheratian et al. (2022)	Stronger focus on survival under sanctions than on a broader multilevel conception of resilience
Specific Industries in Iran	Resilience challenges in pharmaceuticals, medical equipment, and selected industrial supply chains	Bastani et al. (2021); Nikian et al. (2022)	Findings are often sector-specific and may not be fully generalizable to the wider manufacturing sector
Research Gap	Development of a native, multilevel framework for analyzing production resilience in Iran	Present study	Requires analytical integration of firm, supply chain, industry, and state levels

4. Proposed Conceptual Framework: A Multi-level Resilience Model

To conceptualize and interpret production-related pressures in Iranian manufacturing, this study proposes an integrated multilevel framework for analyzing resilience under persistent structural instability. Rather than conceptualizing resilience solely as an internal firm-level dynamic capability, the framework treats it as a context-dependent condition emergent from the systemic interactions across three analytically distinct tiers: the micro level (firm-specific operations), the meso level (inter-firm networks and sectoral dynamics), and the macro level (institutional and macroeconomic conditions). In this formulation, resilience does not reside within a single unit of analysis; rather, it serves as an interpretive architecture to organize how operational shocks, network dependencies, and macro-institutional constraints converge across industrial sectors.

Methodologically, this framework serves as an interpretive and diagnostic structure rather than an empirically validated causal-path model. The empirical baseline utilized in this study, derived from manufacturing Purchasing Managers' Index (PMI) data and official state statistical releases, allows for the identification of broader structural patterns and operational strains across sub-sectors. However, it does not support econometric testing of cross-level causation, micro-level feedback mechanisms, or the internal organizational routines through which dynamic resilience capabilities are institutionalized (Ivanov, 2020; Pettit et al., 2019). Consequently, this framework is operationalized to map and categorize observed industrial pressures across micro, meso, and macro domains.

Micro Level: Operational Adjustment and Buffering Capabilities

At the micro level, the analytical focus centers on the internal shop-floor conditions under which individual enterprises attempt to maintain manufacturing continuity during disruptions. Extant literature characterizes firm-level resilience through mechanisms such as production flexibility, input substitution, dynamic inventory buffering, multi-skilling of labor, and production-line reconfiguration (Hohenstein et al., 2015; Sheffi & Rice, 2005).

These operational buffers allow enterprises to absorb immediate high-frequency shocks and maintain baseline output.

Within the empirical scope of this study, however, these micro-level dynamics must be interpreted with methodological caution. Aggregate PMI sub-indices and macroeconomic production statistics provide proxy indicators of operational stress, such as raw material inventory depletion, surging input costs, and decelerating order books, rather than direct observations of internal managerial capabilities or dynamic adaptation strategies (Cheratian et al., 2022). Consequently, the micro-level tier within this framework designates the functional domain where operational adjustments and tactical buffering occur, retaining an inferential interpretation grounded in descriptive empirical evidence.

Meso Level: Network Dependencies and Sectoral Heterogeneity

The meso level expands the analytical boundary beyond single organizations to encompass the industrial networks, value-chain architectures, and sectoral ecosystems within which manufacturing occurs. Resilience literature associates this meso-tier with multi-tier supplier visibility, inter-firm collaboration, geographical diversification, and network redundancy (Habibi et al., 2023; Pettit et al., 2010; Scheibe & Blackhurst, 2018). These structural parameters determine whether supply-chain shocks are localized, absorbed, or amplified across broader industrial ecosystems through bullwhip and ripple effects.

In this study, cross-sectoral divergences observed in PMI outputs and production indexes serve as descriptive evidence of asymmetric exposure to shocks, rather than direct metrics of inter-firm relational governance. The data highlight distinct sectoral vulnerabilities, including differential exposure to import dependencies, energy grid curtailments, and localized logistics bottlenecks. The meso level thus functions as an analytical layer for interpreting structural asymmetries and inter-firm dependencies across sub-sectors without asserting unverified causal claims regarding shock propagation pathways.

Macro Level: Institutional and Policy Constraints

The macro level captures the structural and institutional matrix governing manufacturing activity. This includes foreign-exchange allocation regimes, capital access frictions, trade barriers, regulatory unpredictability, logistics infrastructure reliability, and industrial energy supply stability. Within the context of Iranian industrial policy under sanctions, these factors represent pervasive structural conditions that dictate operational feasibility rather than secondary background variables (Ahn & Ludema, 2020; Dizaji & van Bergeijk, 2013; Vizvári & Shakeri, 2016).

Nevertheless, the aggregate empirical indicators employed here do not permit exact econometric attribution of single policy interventions to specific manufacturing performance variances. Instead, macro-level indicators are utilized descriptively to establish the boundary conditions of resource allocation and regulatory friction within which industrial enterprises operate. The macro tier thereby establishes the institutional baseline required to contextualize micro-level operational buffering and meso-level supply network strains.

d. Cross-Level Relations and Interpretive Use of the Framework The central proposition of the framework is that production resilience is more plausibly interpreted as a multilevel and relational phenomenon than as a fixed attribute located exclusively at the firm, network, or institutional level. In conditions of overlapping economic, infrastructural, and regulatory pressure, continuity in production may depend not only on internal firm responses, but also on the structure of supply relationships and the stability of the broader policy environment. However, the present study does not test these cross-level relations empirically. Neither the PMI nor the accompanying statistical evidence can establish feedback loops, directional causation, or the relative weight of micro-, meso-, and macro-level influences. For this reason, the framework should be read as a structured interpretive device that helps situate descriptive evidence within a broader analytical architecture. It is intended to support more disciplined interpretation of manufacturing pressures, while avoiding unsupported claims about causal interaction or fully demonstrated resilience. Figure 1 presents this multilevel framework and illustrates the analytical relationship among firm-level adjustment, network dependencies, and institutional conditions under persistent stress.

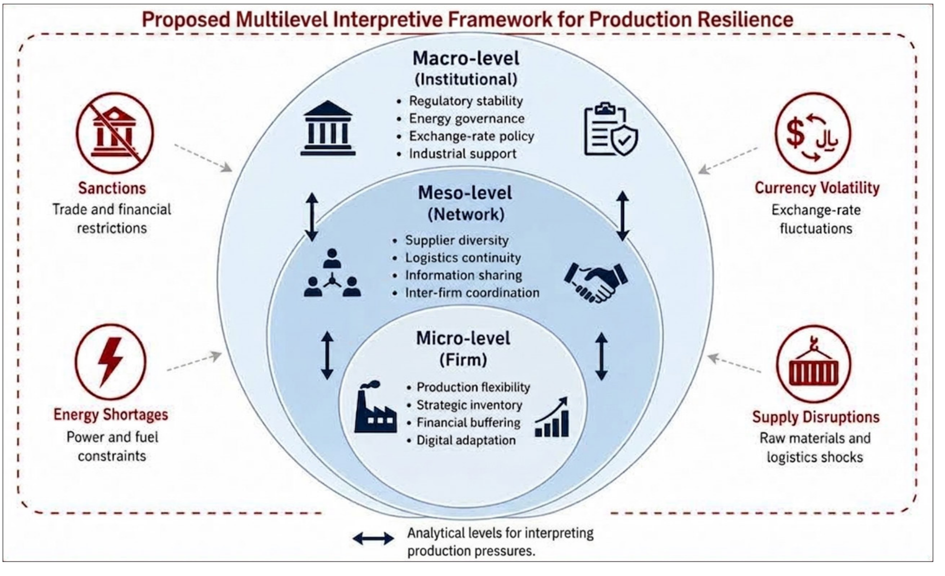

Figure 1. Proposed multilevel interpretive framework linking firm-level adjustment, network dependencies, and macro-institutional conditions in Iranian manufacturing

The figure should be understood as a conceptual map for organizing interpretation, rather than as a validated representation of causal mechanisms.

5. Methodology

This study employs a qualitative-interpretive research design supported by secondary descriptive statistical evidence. The primary analytical objective is neither to quantify production resilience as a single unidimensional observable variable nor to formally test causal relationships through structural econometric modeling. Instead, the study utilizes resilience as an interpretive lens to examine documented production conditions, supply-network vulnerabilities, and macro-institutional pressures operating across the Iranian manufacturing sector under chronic structural instability (Bhamra et al., 2011; Ivanov, 2021).

By adopting this interpretive approach, the study evaluates descriptive data streams, predominantly Purchasing Managers' Index (PMI) indicators and official sector-level statistical releases, to map systemic operational strains across industrial tiers (Pettit et al., 2019). This methodological choice acknowledges that while aggregate secondary data may not capture internal dynamic capabilities or micro-level managerial choices directly, it offers rigorous empirical indicators of operational stress, resource constraints, and cross-sectoral asymmetries under sustained economic disruption (Cheratian et al., 2022; Vizvőri & Shakeri, 2016).

5.1. Research Design and Conceptual Framework

The methodological architecture integrates two distinct analytical components: a conceptual synthesis of the industrial resilience literature and a secondary descriptive analysis of sectoral indicators. The conceptual dimension provides the structural organizing framework, operationalizing three analytical tiers, the micro (firm-level operations), meso (supply network and value-chain relations), and macro (institutional and policy environment) levels, to systematically categorize and interpret the empirical data streams (Hohenstein et al., 2015; Pettit et al., 2010).

Within this methodological setup, these three levels are deployed as analytical categories for structured diagnostic interpretation rather than as empirically verified, deterministic causal tiers. This integrative structure allows the study to bridge high-frequency descriptive indicators with theoretical constructs of operational resilience, supply network vulnerability, and institutional friction without overextending empirical inferences beyond the explanatory power of aggregate secondary data (Bhamra et al., 2011; Ivanov, 2021).

5.2. Data Sources and Scope

The empirical analysis relies exclusively on secondary data, primarily the manufacturing Purchasing Managers' Index (PMI) and official industrial statistics. These materials are treated as officially published records; no primary data collection, such as interviews or firm-level surveys, was conducted. The principal sources include:

- **Manufacturing PMI Reports:** Monthly indices published by the Iran Chamber of Commerce, Industries, Mines and Agriculture (ICCIMA, 2024).
- **Official Statistics:** Sectoral data on financing, energy costs, and production volume released by the Statistical Centre of Iran (SCI, 2024) and relevant industrial

authorities.

5.3. Interpretive Use of PMI Indicators

PMI indicators are used cautiously and in accordance with standard reporting conventions (Institute for Supply Management [ISM], 2023). A value below 50 signifies contraction relative to the previous month, while a value above 50 indicates expansion. Within this study, however, PMI values are not treated as direct measures of “resilience” or “fragility” (Bhamra et al., 2011). Instead, sub-indices, including raw material prices, inventory levels, and supplier delivery times, are interpreted as reported proxies for operational pressure (Pettit et al., 2019). Their meaning is understood to be situated within the original survey’s methodology, weighting procedures, and seasonal adjustments (Iran Chamber of Commerce, Industries, Mines and Agriculture [ICCIMA], 2024).

5.4. Analytical Procedure

The study proceeds in three stages:

1. **Thematic Synthesis:** Reviewing resilience literature to identify dimensions relevant to production continuity under disruption.
2. **Descriptive Mapping:** Examining selected official statistics and PMI trends to identify prominent pressures affecting Iranian manufacturing.
3. **Multilevel Interpretation:** Synthesizing observed statistical patterns through the proposed micro-meso-macro framework to generate a conceptually informed reading of production conditions.

5.5. Methodological Limitations

The study acknowledges several constraints inherent in its design:

- **Operationalization:** Resilience is not directly measured; the analysis focuses on observable pressures and reported conditions that may be associated with resilience.
- **Causality:** Due to the descriptive nature of the secondary evidence, the study does not establish causal mechanisms or demonstrate empirical interaction across analytical levels.
- **Data Reliability:** The analysis is contingent upon the sampling procedures, classification rules, and reporting practices of the original data-producing institutions.

Accordingly, the findings are presented as a structured descriptive interpretation rather than a confirmatory test of a resilience model.

6. Descriptive Analysis of Reported Production Conditions

This section presents a descriptive overview of selected statistical evidence published by official and sectoral reference bodies, with particular attention to manufacturing PMI indicators for May 2026 (Ordibehesht 1405). Its purpose is to document reported production-related conditions and to organize those observations within the article's micro/meso/macro framework. The section does not treat the reported indicators as direct measures of production resilience. Rather, it identifies patterns that may be relevant to the interpretation of production continuity and industrial adjustment under stress (Iran Chamber of Commerce, Industries, Mines and Agriculture [ICCIMA], 2026a). To enhance transparency, each numerical indicator discussed in this section should be linked in the final manuscript to its precise institutional source, report title, publication date, and table or figure number.

6.1. Micro-Level Reported Operating Conditions

The May 2026 manufacturing PMI reported a seasonally adjusted headline value of 45.3, which in standard PMI interpretation indicates contraction relative to the benchmark level of 50 (ICCIMA, 2026a). This reading suggests that surveyed manufacturing activity remained in contractionary territory during the reference month. It does not, by itself, identify the causes of that contraction. Several sub-indices provide additional descriptive information about reported operating conditions. The raw-material purchase-price index was reported at 92.4, indicating a high incidence of reported increases in input purchase prices within the PMI survey framework (ICCIMA, 2026a). The raw-material inventory index stood at 36.3, which is consistent with relatively weak inventory conditions as reported by surveyed firms (ICCIMA, 2026a). The energy-consumption index was 49.5, while the sales index was 41.5; both remained below the neutral threshold of 50 (ICCIMA, 2026a). Taken together, these indicators describe a difficult reported operating environment characterized by contractionary survey readings, elevated input-price pressures, weak inventory conditions, and subdued sales. These observations may be relevant to the analysis of production continuity at the firm level. However, the available data do not permit direct causal inference, nor do they directly measure firm resilience.

6.2. Meso-Level Sectoral PMI Patterns

The sectoral PMI data indicate that reported manufacturing conditions varied across industries during the same period. Some sectors recorded readings above 50. For example, rubber and plastics reported 60.2, and wood, paper, and furniture reported 51.5. Other sectors remained below 50, including apparel and leather at 41.1. Sectoral sub-indices also show noticeable variation. In the automotive sector, for example, the raw-material inventory index was reported at 28.6, suggesting relatively weak inventory conditions in that sector. Similar differences appear across other industries in relation to input prices, inventories, and output-related indicators. At the descriptive level, these results point to heterogeneity in reported industrial conditions rather than a uniform manufacturing pattern. The data do not identify why these differences occur. They may be associated with variation in input dependence, supply-chain structure, foreign-exchange exposure, market conditions, technical production requirements, or energy intensity, but these mechanisms are not directly tested in this article. For that reason, the sectoral evidence is used here to document variation, not to establish explanatory hierarchy.

6.3. Macro-Level Institutional and Financial Context

Additional official statistics provide descriptive evidence on broader production-related conditions beyond the PMI survey. One reported pattern concerns the relationship between industry's economic weight and its direct tax burden. According to the cited official statistics, industry accounts for approximately 19.2 percent of GDP while contributing about 32 percent of direct tax revenues (Iranian National Tax Administration [INTA], 2026; Statistical Centre of Iran [SCI], 2026). This comparison may be read as suggesting a relatively heavy fiscal burden on industry, although the statistic alone does not establish its precise effect on firm behavior, investment, or output. A second pattern concerns the structure of industrial finance. Official data indicate that working-capital financing accounted for 87.7 percent of total industrial financing in the reported period (Central Bank of the Islamic Republic of Iran [CBI], 2026). This suggests a financing profile concentrated on short-term operating needs. However, this figure does not directly reveal how firms allocated funds internally, nor does it by itself demonstrate underinvestment in modernization. It nevertheless provides descriptive evidence consistent with a short-term financing orientation. A third pattern concerns regulatory and infrastructural conditions reported by sectoral and institutional sources. These include references to regulatory unpredictability, bureaucratic delays, customs frictions, energy cost increases, and recurrent power or fuel constraints (Iran Chamber of Commerce, Industries, Mines and Agriculture [ICCIMA], 2026b). These reported conditions are relevant because they may shape the broader environment within which production decisions are made. Even so, the present article treats them as contextual descriptive evidence rather than as directly quantified determinants of resilience.

6.4. Descriptive Synthesis

The evidence reviewed in this section points to three broad categories of reported pressure. First, financial and price-related pressures are reflected in high reported input-price readings and evidence of strong reliance on working-capital financing. Second, institutional and fiscal pressures are reflected in taxation patterns and reported regulatory frictions. Third, infrastructural pressures are especially visible in energy cost and supply conditions. Within the logic of this article, these categories are organized analytically across the micro, meso, and macro levels. This organization should be understood as an interpretive classification of the observed evidence, not as proof of empirically demonstrated interaction across levels. The main contribution of this section is therefore descriptive: it shows that reported production conditions in Iran appear to involve multiple types of pressure operating at different analytical scales.

7. Discussion

The descriptive evidence presented in Section 6 suggests that manufacturing conditions in Iran may be more meaningfully interpreted through a multilevel perspective than through a narrowly firm-centered one (Hohenstein et al., 2015; Pettit et al., 2019). This claim should be understood in a limited analytical sense. The article does not empirically validate a multilevel resilience model through causal testing or confirmatory analysis. Rather, it shows that the available descriptive evidence can be organized coherently across firm-level operating conditions, sectoral variation, and the broader institutional context (Cheratian et al., 2022; Ivanov, 2021).

A central implication of this interpretation is conceptual. The data reviewed in this article do not directly measure production resilience (Bhamra et al., 2011). Instead, they describe reported pressures, contractions, asymmetries, and constraints that may be relevant to production continuity and adaptive behavior (Habibi et al., 2023; Sheffi & Rice, 2005). For this reason, resilience is treated here as an analytical construct used to interpret the significance of the observed evidence, rather than as an empirically measured outcome demonstrated by the data.

7.1. Firm-Level Interpretation

At the micro level, the PMI evidence suggests that many firms were operating in a difficult reported environment during the reference period. Elevated input-price readings, weak inventory indicators, soft sales, and sub-50 energy-related readings together point to strained operating conditions (Habibi et al., 2023; Iran Chamber of Commerce, Industries, Mines and Agriculture [ICCIMA], 2026a). These observations are relevant to resilience analysis because they may indicate limited room for maneuver in procurement, scheduling, and liquidity management (Bhamra et al., 2011; Sheffi & Rice, 2005).

At the same time, caution is necessary. The data do not show how individual firms responded internally, which firms adapted more effectively than others, or which managerial practices were most consequential (Pettit et al., 2019; Vizvőri & Shakeri, 2016). Accordingly, the article cannot conclude that firm-level resilience was low in any direct measured sense. A more defensible interpretation is that the observed conditions appear consistent with pressure on production continuity at the firm level (Cheratian et al., 2022).

7.2. Sectoral Interpretation

At the meso level, the sectoral PMI results indicate that reported manufacturing conditions were uneven across industries. This is analytically important because it suggests that industrial conditions were not homogeneous during the reference period. Some sectors reported relatively stronger readings, while others remained well below the contraction threshold (Cheratian et al., 2022; Iran Chamber of Commerce, Industries, Mines and Agriculture [ICCIMA], 2026a).

The article interprets this heterogeneity as relevant to the meso level because sectoral structure and network position may influence how pressures are experienced and managed (Hohenstein et al., 2015; Pettit et al., 2010). However, the present evidence does not directly observe supply-network configuration, inventory strategies across networks, or actual inter-firm coordination mechanisms (Ivanov, 2021; Sheffi & Rice, 2005). The article therefore stops short of claiming that meso-level mechanisms have been demonstrated empirically. Instead, it argues that sectoral variation makes a meso-level analytical lens useful for interpretation (Bhamra et al., 2011; Habibi et al., 2023).

7.3. Macro-Level Interpretation

At the macro level, the fiscal, financial, regulatory, and energy-related evidence suggests that manufacturing firms operate within a broader institutional environment that may shape production conditions (Farzanegan & Hayo, 2019; North, 1990). Taxation patterns, reliance on working-capital finance, and reported regulatory and infrastructural frictions all appear relevant to the conditions under which industrial activity is sustained under stress (Central Bank of the Islamic Republic of Iran [CBI], 2026; Islamic Parliament Research Center [IPRC], 2025; Vizvőri & Shakeri, 2016).

Here again, the article does not claim that these macro conditions have been causally shown to determine production outcomes. Rather, it argues that the descriptive evidence makes it difficult to interpret firm-level conditions in isolation from the broader institutional setting (Acemoglu et al., 2005; Cheratian et al., 2022). In that limited but important sense, the macro dimension appears analytically significant (Habibi et al., 2023; Scott, 2014).

7.4. Survival-Oriented Adjustment as a Conceptual Reading

One useful interpretive distinction emerging from the evidence is that between survival-oriented adjustment and strategic resilience (Bhamra et al., 2011; Lengnick-Hall et al., 2011). The available data do not directly operationalize either concept. Nonetheless, the descriptive pattern of strong working-capital orientation, difficult input conditions, weak inventories, and unstable infrastructure appears more consistent with short-term continuity management than with clearly observable long-term strategic upgrading (Central Bank of the Islamic Republic of Iran [CBI], 2026; Cheratian et al., 2022; Iran Chamber of Commerce, Industries, Mines and Agriculture [ICCIMA], 2026a; Islamic Parliament Research Center [IPRC], 2025).

This distinction should therefore be presented as a conceptual reading of the evidence rather than as a directly measured conclusion (Pettit et al., 2019; Vizvőri & Shakeri, 2016). It helps clarify why continued production under stress should not automatically be equated with robust resilience in a developmental or strategic sense (Duchek, 2020; Habibi et al., 2023).

7.5. Implication for the Framework

Overall, the framework proposed in this article is useful primarily as an interpretive device for organizing evidence across multiple analytical levels (Bhamra et al., 2011; Pettit et al., 2019). It does not empirically prove that these levels interact in a formally tested way, nor does it establish a hierarchical model of causation (Cheratian et al., 2022; Vizvőri & Shakeri, 2016). What it does show is that the observed descriptive evidence can be read more coherently when firm-level indicators, sectoral variation, and institutional context are considered together rather than in isolation (Duchek, 2020; Habibi et al., 2023; Scott, 2014).

8. Policy Implications

Because the empirical evidence used in this article is descriptive, the policy implications offered here should be understood as evidence-informed and conditional rather than as directly validated prescriptions. Each implication is linked to a pattern observed in the reported data, but the article does not test the effectiveness of the proposed interventions (Pettit et al., 2019; Vizvбri & Shakeri, 2016).

8.1. Firm-Level Implications

The PMI evidence reports elevated input-price pressure and weak inventory conditions (Iran Chamber of Commerce, Industries, Mines and Agriculture [ICCIMA], 2026a). These patterns suggest that firms may benefit from strengthening procurement monitoring, diversifying suppliers where feasible, and improving contingency planning for critical inputs (Bhamra et al., 2011). The relevance of these implications derives from the reported price and inventory indicators, not from direct evidence that such strategies would be equally effective across all sectors or firms. The sales and financing evidence likewise suggests that tighter working-capital management may become more important under contractionary conditions (ICCIMA, 2026a). Where firms face soft demand, rising input costs, and a concentration of financing in short-term operating facilities, closer coordination among purchasing, production, and cash-flow planning may help reduce exposure to short-term disruption (Cheratian et al., 2022). Finally, sub-50 energy-related readings, together with broader evidence on energy instability, point to the potential importance of firm-level energy contingency planning (ICCIMA, 2026a; Ministry of Energy, 2026). This may include revised production scheduling, backup arrangements where economically feasible, and greater attention to energy efficiency in continuity planning (Habibi et al., 2023).

8.2. Industry-Level Implications

The sectoral PMI evidence indicates uneven reported conditions across industries (ICCIMA, 2026a). This suggests that a uniform industrial support strategy may be less appropriate than sector-sensitive approaches. Sectors with lower PMI readings and weaker inventory conditions may require different forms of coordination and support from those with relatively stronger short-term performance (Hohenstein et al., 2015). The observed heterogeneity also supports the view that sectoral associations, chambers, and coordinating institutions may play a useful role in information sharing and bottleneck reporting. Where sectors are highly exposed to input bottlenecks, collaborative procurement, shared market intelligence, or more structured reporting of supply constraints may also deserve consideration (Ivanov, 2021).

8.3. Macro-Level Implications

The broader financial, fiscal, regulatory, and infrastructural evidence suggests that policy predictability may matter for production continuity (North, 1990). Where firms operate under unstable regulatory, financing, and energy conditions, clearer and more consistent institutional rules may improve planning conditions (Farzanegan & Hayo, 2019). The concentration of industrial finance in working-capital facilities also suggests that policymakers may wish to consider whether the existing financing structure leaves sufficient room for modernization, adaptation, and capability upgrading (Central Bank of the Islamic Republic of Iran [CBI], 2026). The evidence on energy costs and supply instability likewise points to the possible importance of industrial energy governance. More transparent pricing, more reliable supply arrangements, and clearer shortage-management mechanisms may be especially relevant in an environment where energy appears repeatedly in the descriptive evidence as a production-related constraint (Islamic Parliament Research Center [IPRC], 2025).

8.4. Integrated Implication

Taken together, the evidence suggests that production-related pressures are distributed across operational, sectoral, and institutional levels. For that reason, an integrated policy approach may be more appropriate than interventions focused on only one level. This should be read as a policy inference from the structure of the observed evidence, not as a tested claim about optimal policy design (Scott, 2014).

9. Conclusion

This article examined production-related pressures in Iranian manufacturing through a conceptual multilevel framework supported by secondary descriptive evidence (Bhamra et al., 2011; Scott, 2014). Rather than directly measuring production resilience or testing causal relationships, the study used resilience as an interpretive concept for organizing evidence on firm-level operating conditions, sectoral PMI variation, and the broader institutional and infrastructural context (Duchek, 2020; Pettit et al., 2019). The descriptive evidence indicates contractionary manufacturing readings during the reported PMI period, elevated input-price pressure, weak inventory conditions, uneven sectoral performance, strong reliance on working-capital finance, and broader fiscal, regulatory, and energy-related pressures (Central Bank of the Islamic R0; Pettit et al., 2019). The descriptive evidence indicates contractionary manufacturing readings during the reported PMI period, elevated input-price pressure, weak inventory conditions, uneven sectoral performance, strong reliance on working-capital finance, and broader fiscal, regulatory, and energy-related pressures (Central Bank of the Islamic Republic of Iran [CBI], 2026; Iran Chamber of Commerce, Industries, Mines and Agriculture [ICCIMA], 2026a; showing that these observed pressures can be interpreted through a micro/meso/macro framework in a way that highlights the layered character of industrial conditions (Cheratian et al., 2022; Habibi et al., 2023). This should not be read as an empirical validation of cross-level interaction. Rather, it is a structured interpretive approach that helps relate firm-level indicators to sectoral variation and broader institutional context (Hohenstein et al., 2015; North, 1990). A further interpretive implication is that continued production under stress may, in some cases, be more appropriately understood as survival-oriented adjustment rather than as demonstrated strategic resilience (Lengnick-Hall et al., 2011). In the present article, this distinction remains conceptual and inferential. It therefore requires more direct examination in future research through firm-level surveys, comparative case studies, or longitudinal analysis (Ivanov, 2021).

The study also has clear limitations. It relies on secondary data, does not directly operationalize resilience through a validated indicator, and does not establish causal effects (Sheffi & Rice, 2005). In addition, the explanatory value of the analysis depends on the quality, scope, and transparency of the original data sources (Farzanegan & Hayo, 2019). Future research could strengthen the framework by incorporating firm-level evidence, clearer operational indicators, and more systematic comparison across sectors and time periods (Ministry of Energy, 2026).

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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

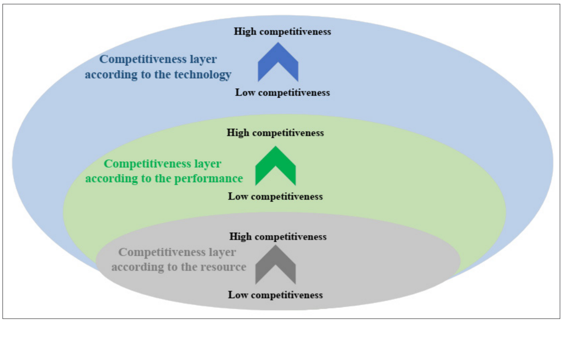
Another challenge is the business environment and the specific characteristics and level of development of each sector of the economy. The combination of technological capabilities within firms differs across countries; therefore, a one-size-fits-all policy cannot be applied universally. To resolve this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

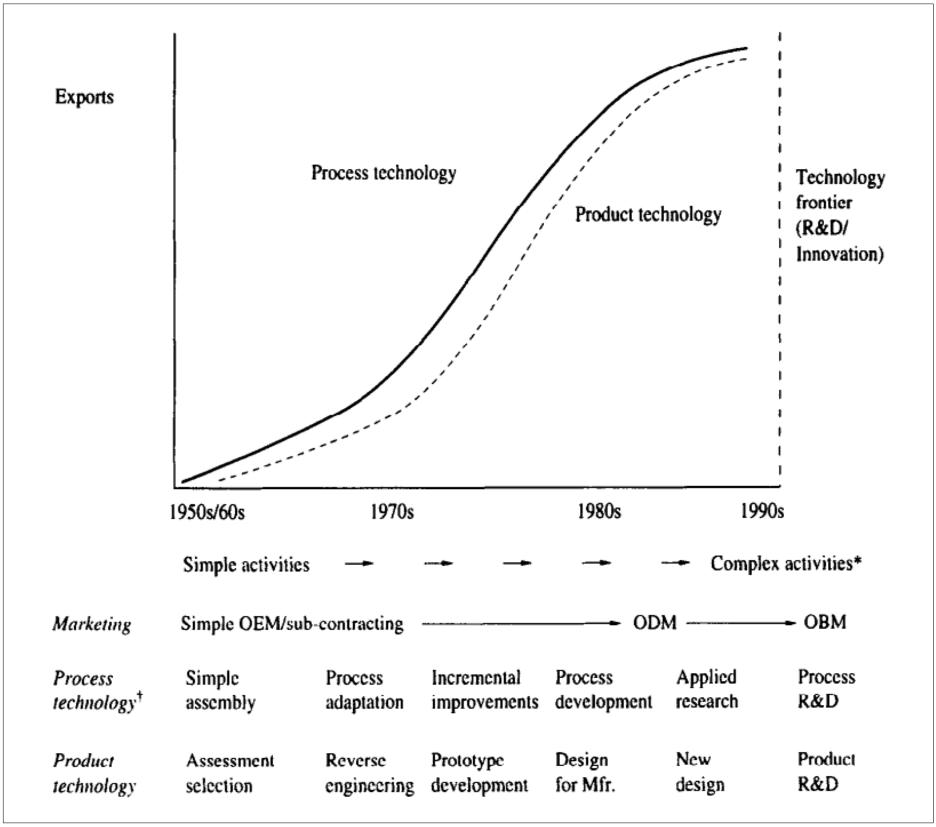


Figure 2 - Hobday's path of technology catch-up (Hobday, 1995)

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.

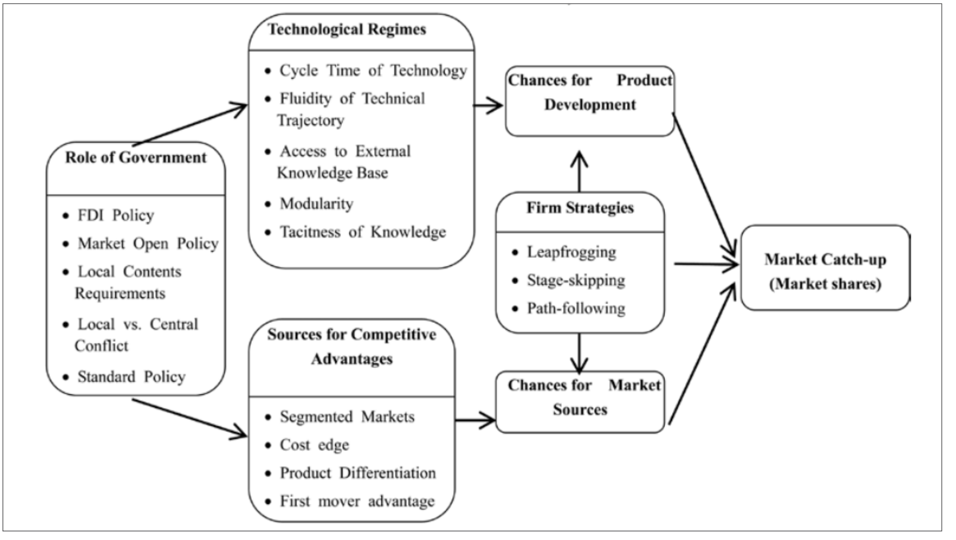


Figure 3 – Lee et al. model of catch-up (Lee et al., 2017)

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.

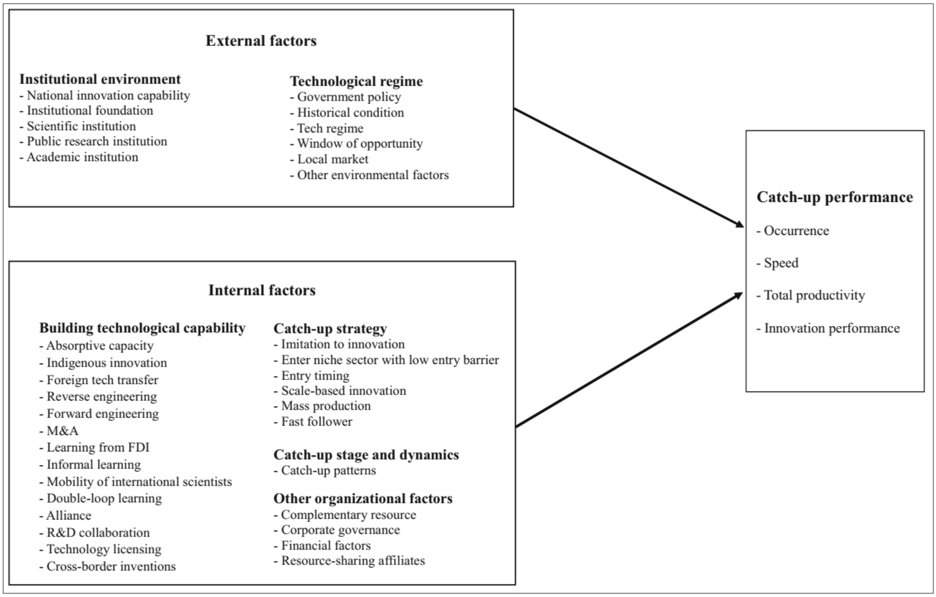


Figure 4- Miao et al. model of technology catch-up (Miao et al., 2018)

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.

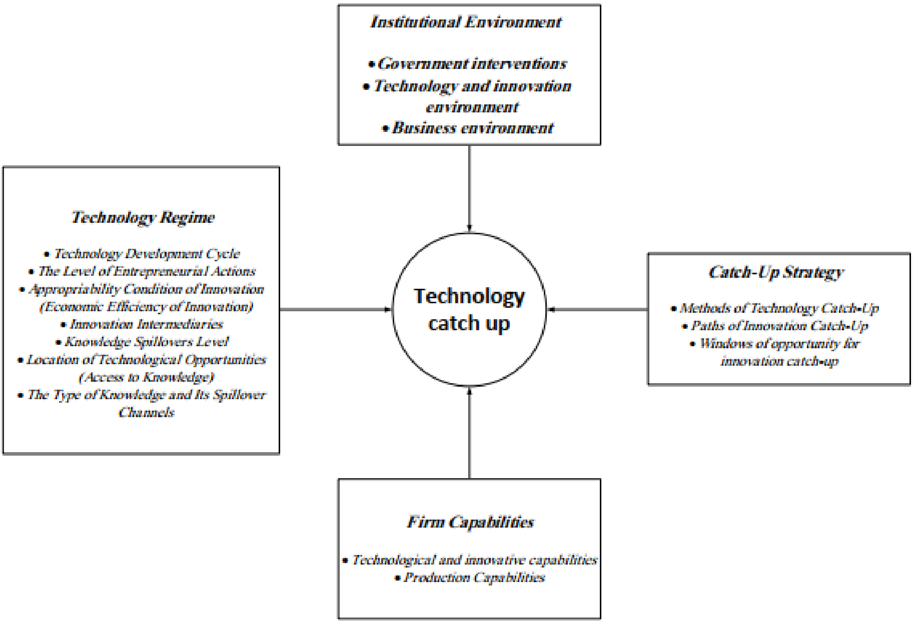
For Iran, these developments are particularly relevant because the country’s catch-up process combines substantial scientific and engineering capacity with institutional constraints, sanctions-related barriers to technology and finance, and uneven firm-level capabilities. The recent Iranian literature 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).

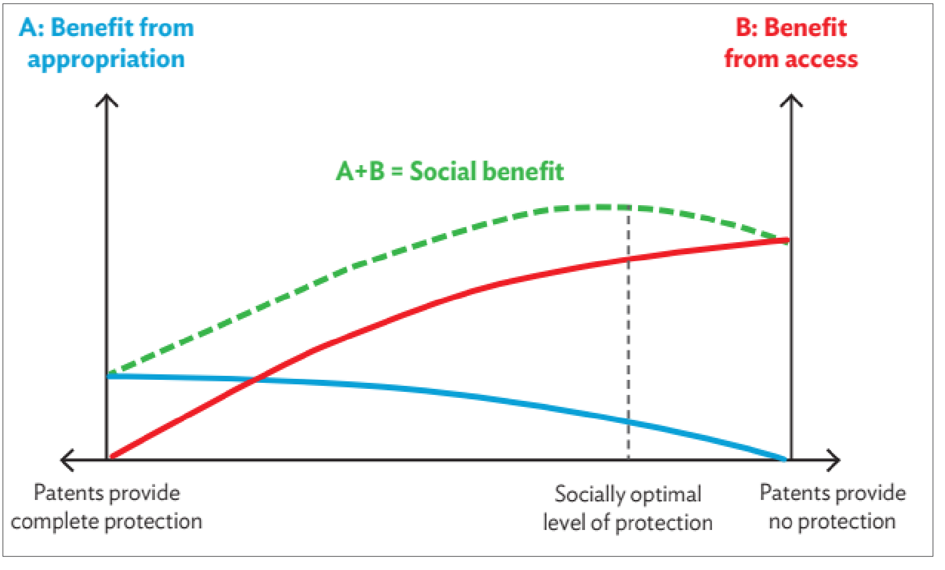


Figure 6- Conflict between the interests of appropriation and access to knowledge and technology (Ambashi, 2017)

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.

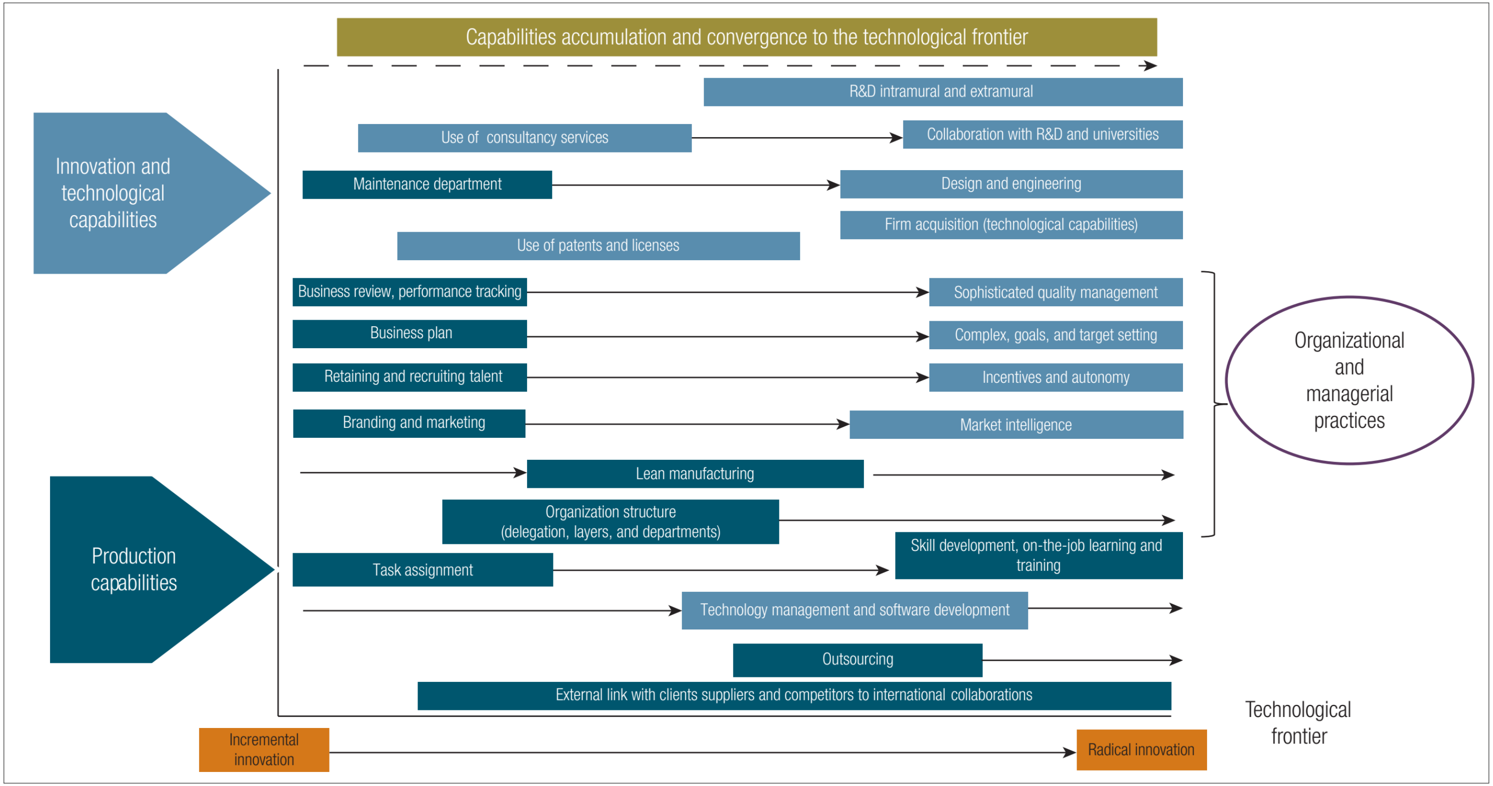
From another perspective, technological capabilities within the firm refer to a set of actions the company takes to increase its ability to develop technology. These actions include the capacity to attract, identify, and take advantage of knowledge and technology spillovers, internal R&D, and skilled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

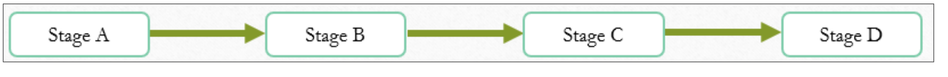


Figure 8- Path Following Catching Up

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.

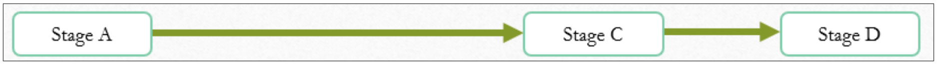


Figure 9- Path skipping catching up

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. Tъrkiye’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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Technological Capability Assessment of Iranian Confectionery and Chocolate Manufacturers: An Approach Based on the AFRICP Model

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Abstract

The Iranian confectionery and chocolate industry has considerable potential for industrial upgrading, employment generation, and regional export development. Nevertheless, the accumulation of production capabilities has not translated proportionately into stable access to international markets and stronger inter-firm and institutional linkages. This study assesses the technological capabilities of leading Iranian confectionery and chocolate manufacturers and identifies the principal capability gaps and upgrading constraints. Drawing on an evolutionary perspective on technological learning and a capability-based framework adapted from the AFRICP approach, the study examines five dimensions: function, product, production process, end market, and linkages. An exploratory mixed-method design was employed, combining semi-structured interviews and structured capability scoring among ten leading firms with export experience and established domestic brands. To improve methodological transparency, dimension-specific scoring rules and an explicit aggregation procedure were applied. Because the end-market indicator showed no quantitative variation across the ten firms, its numerical score was treated as a descriptive indicator rather than as a discriminating component of the composite capability index; the distinction between domestic market strength and international market capability was subsequently examined through qualitative evidence. The findings indicate relatively strong capabilities in production processes and products, while substantial heterogeneity remains in functional capabilities and linkages. In particular, institutional and inter-firm linkages are weak, and international market relationships are often temporary and vulnerable to sanctions, currency-transfer constraints, and exchange-rate volatility. The results suggest that technological capability accumulation in the industry has been stronger than its conversion into sustained international market access and systemic upgrading. Accordingly, policy interventions should simultaneously address firm-level capability deepening, inter-firm and institutional coordination, export-market diversification, workforce development, and the institutional conditions required for learning and innovation.

Keywords: Technological Capabilities; Confectionery and Chocolate Industry; AFRICP Framework

چکیده

صنعت شیرینی و شکلات ایران از پتانسیل بالایی در ارتقای صنعتی، اشتغال‌زایی و توسعه صادرات منطقه‌ای برخوردار است. با این حال، انباشت قابلیت‌های تولیدی در این بخش به‌طور متناسب به نفوذ پایدار در بازارهای جهانی و شکل‌گیری پیوندهای مستحکم بین‌بنگاهی و نهادی منجر نشده است. این مطالعه با اتکا به رویکرد تکاملی یادگیری فناورانه و چارچوب قابلیت‌محورِ برگرفته از مدل AFRICP، توانمندی‌های فناورانه شرکت‌های پیشرو را در پنج بعد «کارکرد»، «محصول»، «فرآیند تولید»، «بازار نهایی» و «پیوندها» ارزیابی می‌کند. پژوهش با روش آمیخته اکتشافی و از طریق مصاحبه‌های نیمه‌ساختاریافته و امتیازدهی ساختاریافته به ۱۰ بنگاه پیشتاز و صادرات‌محور انجام پذیرفته است. یافته‌ها مبین استحکام قابلیت‌ها در ابعاد فرآیند تولید و تنوع محصول است؛ اما ناهمگونی شدیدی در قابلیت‌های کارکردی و ضعف مفرط در پیوندهای نهادی و بین‌بنگاهی به چشم می‌خورد. افزون بر این، حضور در بازارهای بین‌المللی عمدتاً شکننده، کوتاه‌مدت و متأثر از تکانه‌های ارزی، تحریم و چالش‌های نقل‌وانتقال مالی است. نتایج نشان می‌دهد انباشت قابلیت‌های فناورانه بر ظرفیت تبدیل آن‌ها به نفوذ پایدار تجاری و ارتقای سیستمی پیشی گرفته است. بنابراین، مداخله سیاست‌گذار باید هم‌زمان بر عمق‌بخشی به قابلیت‌های درون‌بنگاهی، توسعه هماهنگی‌های نهادی و شبکه‌ای، تنوع‌بخشی به مقاصد صادراتی، ارتقای سرمایه انسانی و بهبود زیرساخت‌های نهادی یادگیری و نوآوری متمرکز گردد.

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1. Introduction

Industrial development in emerging economies has always been intertwined with the issue of "learning" and "accumulation of technological capabilities" (Amsden, 2001; Lall, 1992). Unlike neoclassical approaches that view technology as a public good readily transferable, the evolutionary economics approach emphasizes that technology comprises tacit knowledge and firm-specific routines that can only be acquired through experience, trial and error, and learning by doing (Nelson & Winter, 1982). From this perspective, industrial competitiveness depends not merely on production costs or cheap labor, but on the extent and depth of technological capabilities accumulated within firms (Khan, 2009; Lall, 1992).

The Iranian confectionery and chocolate industry represents a significant segment of the country's food-processing sector and has developed a substantial domestic production base and export presence. Available official statistics indicate significant production and trade activity in the sector; however, because monetary values and revenue changes in Iran are strongly affected by inflation and exchange-rate movements, nominal market-value and revenue-growth figures should be interpreted cautiously. Accordingly, this study does not use nominal revenue growth as evidence of real industrial expansion and focuses instead on firm-level technological capabilities, production performance, market relationships, and upgrading constraints (Statistical Center of Iran, 2020; Islamic Republic of Iran Customs Administration, 2023). Nevertheless, despite qualitative achievements (such that the quality of products from some factories is comparable to European samples), this industry has not been able to gain a worthy position in global markets, and its export share remains negligible.

The main research question is why, despite the efforts of confectionery and chocolate manufacturers over the past years, this industry has failed to achieve desired competitiveness. Answering this question requires going beyond macroeconomic analyses and entering the firm level, studying technological capabilities; because as Bell and Pavitt (1995) argue, technological capabilities are "intangible and non-transferable capital" that underpin the structural transformation of the national economy and diversification into new products and industries.

Accordingly, the main objective of this research is to assess the technological capabilities of leading firms in the Iranian confectionery and chocolate industry using a capability-based framework adapted from the AFRICP approach and the broader technological-capability literature. The framework used in this study focuses on five analytically distinct dimensions: function, product, production process, end market, and linkages. The first four dimensions capture firms' ability to undertake increasingly sophisticated value-adding activities and participate in domestic and international markets, while the linkage dimension captures the relational and institutional capabilities required for learning, knowledge exchange, and upgrading (Lall, 1992; Morrison et al., 2008).

The use of this framework in the confectionery and chocolate industry requires an explicit adaptation because the underlying capability literature has been applied across different industrial contexts. The present study therefore does not assume that an industry-specific framework developed for another sector can be transferred mechanically to food manufacturing. Instead, the dimensions and indicators were contextualized to the technological, production, market, and inter-organizational characteristics of confectionery and chocolate manufacturing. In particular, product complexity and variety, production quality and reliability, market relationships, andinter-firm and institutional linkages were operationalized according to the characteristics of theIranian confectionery and chocolate value chain. This adaptation is consistent with the capability literature, which emphasizes that technological capabilities are context-dependent and embedded in firm-specific learning processes (Lall, 1992; Morrison et al., 2008).

The significance of this study is therefore not the application of AFRICP as a universal industrytemplate, but its contextual adaptation as an analytical device for examining technologicalcapability accumulation and upgrading constraints in an Iranian food-processing industry.

2. Theoretical Framework and Literature Review

2-1. The Concept of Technological Capabilities: From Evolutionary Economics to the Firm-Level Approach

The theoretical roots of the concept of "technological capabilities" go back to evolutionary economics and the foundational works of Nelson and Winter (1982). In this theoretical tradition, the firm is conceptualized as "a set of routines" that are formed over time through learning, trial and error, adaptation, and imitation. These routines include not only codified knowledge but also tacit dimensions embedded in individual skills, organizational structures, and patterns of social interaction (Bell & Pavitt, 1995). Hence, technology transfer is not possible merely by purchasing machinery or obtaining technical documents; it requires "learning by doing" and "problem- solving" in the specific contexts of each firm (Lall, 1993).

Lall (1992, 1996), systematizing these concepts, divides technological capabilities into three general categories: (1) **"Investment capabilities"** – skills needed to identify, evaluate, design, construct, equip, and commission new facilities; (2) **"Production capabilities"** – skills necessary for the efficient operation of a production unit and its continuous improvement through quality control, maintenance, inventory management, and innovation in processes and products; and (3) **"Linkage capabilities"** – communication skills and relationship management with suppliers, buyers, consultants, research institutions, and government agencies. Each of these categories can also be distinguished at three levels of complexity (basic, intermediate, advanced) (Biggs et al., 1995).

A key concept in the technological capabilities literature is the distinction between "static efficiency" and "learning dynamics." Firms may achieve a certain level of productivity using existing technology, but to maintain competitiveness in the long run they need continuous investment in “technological efforts” including training, R&D, acquisition and adaptation of new technologies, and organizational improvement (Lall, 1993; Khan, 2013). These efforts always involve risk and uncertainty, because the learning path and the time to achieve competitive productivity cannot be predicted in advance.

2-2. The AFRICP Model: A Matrix for Assessing Technological Capabilities

The AFRICP model, conceptually formulated by Lall (1992) and operationalized by UNIDO for various industries, provides a matrix framework for assessing technological capabilities at the firm level (Morrison et al., 2008). In this model, technological capabilities are classified into four main dimensions: “Product” (complexity and variety of manufactured products), **“Production process”** (quality, reliability, productivity, and compliance with standards), **“End market”** (number and stability of relationships with buyers and distribution channels), and **“Linkages”** (relationships with other firms, suppliers, government and educational institutions). To these four dimensions, a fifth dimension, **“Function”**, is added, which specifies the firm’s position in the value chain from simple assembly for others (OEM) to custom design (ODM) and finally own-brand manufacturing (OBM) and turnkey (Gereffi, 1999).

The extended matrix in the present study (Table 1) integrates Lall’s approach with global value chain literature. The vertical axis of this matrix corresponds to **“functional upgrading,”** meaning that moving toward higher functions in the value chain (from mere production to design, branding, logistics, and distribution) requires more complex and advanced capabilities (Humphrey & Schmitz, 2002). The horizontal axis details the five capability dimensions at three levels of complexity (basic, intermediate, advanced). This matrix enables analysis of both **“horizontal upgrading”** (deepening capabilities within a given function) and **“vertical upgrading”** (moving to higher functions).

Table 1: Technological Capability Assessment Matrix Adapted to the Iranian Confectionery and Chocolate Industry

Capability dimension	Basic	Intermediate	Advanced
Function	Turnkey production based mainly on established routines	Turnkey production with strong branding and market coordination	Strong own-brand capabilities combined with advanced design, marketing and value-chain functions
Product	Simple and standardized products with limited variety	Moderate variety and complexity	High variety, product differentiation and technically complex products
Production process	Basic quality control and limited process standardization	Formal quality-management systems and process improvement	Advanced quality systems, multiple international standards, high reliability and continuous process innovation

Capability dimension	Basic	Intermediate	Advanced
End market	Concentration on a limited number of domestic buyers/ channels	Multiple domestic channels and relatively stable buyer relationships	Diversified domestic and international markets with stable export relationships
Linkages	Limited relationships with suppliers and other firms	Formal supplier relationships and emerging industry collaboration	Extensive vertical and horizontal linkages, institutional collaboration and joint learning/R&D

Table 1 presents the operational capability dimensions used in the empirical analysis. Investment capability and logistics/supply-chain finance are not treated as independent measured dimensions in the present study because the interview instrument did not generate sufficiently systematic indicators for their quantitative assessment. They are therefore considered contextual factors that may influence capability accumulation rather than direct components of the empirical capability index. This distinction is important for maintaining consistency between the conceptual framework, measurement instrument, and empirical analysis.

2-3. Linking Technological Capabilities to Upgrading in Global Value Chains

In the last two decades, the global value chains (GVC) literature has provided a powerful framework for analyzing industrial dynamics and upgrading paths of firms in the global economy (Gereffi et al., 2005; Coe & Yeung, 2015). Upgrading in this literature refers to the process by which firms improve their position in the hierarchy of value-added activities (Bair & Gereffi, 2003). Humphrey and Schmitz (2001, 2002) distinguish four types of upgrading: (1) process upgrading (increasing production efficiency), (2) product upgrading (moving to higher quality and more complex products), (3) functional upgrading (changing the mix of activities toward design, branding, and marketing), and (4) end-market upgrading (diversifying export markets). Later studies have added supply chain upgrading (creating backward linkages) and inter-chain upgrading (entering related industries) (Frederick & Staritz, 2011).

The intersection of technological capabilities and GVC literature lies in the fact that **"technological capabilities underpin the realization of all types of upgrading"**. In other words, without accumulating necessary capabilities in product, process, market, and linkages, no upgrading is possible (Morrison et al., 2008; Pietrobelli & Rabellotti, 2006). However, one should not assume that upgrading is always a linear and upward process. Empirical research has shown that firms may pursue multiple strategies simultaneously: some maintain simple, low- value production, others enter regional markets while simultaneously building own brands for the domestic market (Tokatli, 2013; Pickles et al., 2006). Also, functional upgrading (especially moving to design and branding) is often more successful in domestic and regional markets than in global markets, because global lead firms tend to keep these high-value-added activities within their core competencies (Kaplinsky & Morris, 2001; Navas-Aleman, 2011).

Drawing on the above theoretical framework, this research assesses the technological capabilities of Iranian confectionery and chocolate firms and attempts to identify potential upgrading paths considering the country's specific conditions (sanctions, exchange rate fluctuations, import restrictions).

3. Research Methodology

3-1. Research Approach

The present study employs an "exploratory-explanatory mixed methods" approach. Mixed methods were chosen because assessing technological capabilities requires a combination of quantitative data (scores, percentages, counts) and qualitative data (understanding learning processes, analyzing relationships and linkages, institutional contexts) (Creswell & Clark, 2017). The qualitative part was conducted through semi-structured in-depth interviews, and the quantitative part through a questionnaire derived from the AFRICP model and the scoring guide table.

3-2. Population and Sampling

The research population includes "leading firms in the Iranian confectionery and chocolate industry". Criteria for being leading were: (1) having export experience in the last 5 years (as an indicator of competitive ability in foreign markets) and (2) having a recognized domestic brand (as an indicator of marketing capability and brand investment). After consulting experts and managers of the Iranian Confectionery and Chocolate Industry Association, an initial list of 15 firms was prepared. Of these, after repeated follow-ups and sending formal requests to the association, interviews with stakeholders from "10 firms" were possible (response rate 67%). Each interview lasted between 2 to 8 hours, and in some cases, the interview was conducted in two multi-hour sessions. Interviewees included CEOs, production managers, quality managers, and export managers of the firms.

3-3. Data Collection Instrument and Scoring Procedure

The main research instrument was a "semi-structured questionnaire" derived from the AFRICP model, validated in previous studies (e.g., Biggs et al., 1995; Morrison et al., 2008). This questionnaire comprised five main sections:

1. **"Function":** Questions about the type of firm activities in the value chain (OEM, ODM, OBM, turnkey).
2. **"Product":** Questions about complexity and variety of manufactured products, number of main products, average unit price.
3. **"Production Process":** Questions about on-time delivery rate, internal reject rate (waste and rework), standard certifications (ISO, BSCI, WRAP, ISO 14001), quality control systems.

4. **“End Markets”:** Questions about number of main buyers and sales channels, stability of buyer relationships, history of losing buyers.
5. **“Linkages”:** Questions about collaboration with other firms (horizontal), relationships with input and service suppliers (vertical), relations with government institutions and industry associations, participation in joint projects.

The main research instrument was a semi-structured questionnaire derived from the capability dimensions identified in the theoretical framework. The instrument contained five capability dimensions: function, product, production process, end market, and linkages. Each indicator was scored on a three-point ordinal scale, where higher values represented greater technological capability. The scoring criteria were defined prior to the assessment and were applied consistently across all ten firms.

Function was assessed on a four-point maximum scale because the observed firms were predominantly operating at the turnkey level, with the distinction between standard turnkey production and turnkey production supported by strong own-brand capabilities. Product capability was assessed through two indicators, product complexity and product variety, with a maximum score of six. Production-process capability was assessed through three indicators, delivery reliability, internal rejection/rework, and certification/quality-management systems, with a maximum score of nine. End-market capability was initially assessed through buyer/ channel breadth and relationship stability, with a maximum score of six. Linkage capability was assessed through horizontal inter-firm relations, vertical supplier relations, and relations with government and industry institutions, with a maximum score of nine.

For each dimension, the score was obtained by summing the scores of its constituent indicators. The following thresholds were used for dimension-level interpretation:

Table 2: Scoring Procedure

Dimension	Maximum score	Low	Medium	High
Function	4	2	3	4
Product	6	2–3	4–5	6
Production process	9	3–5	6–7	8–9
End market	6	2–3	4–5	6
Linkages	9	3–5	6–7	8–9

The overall capability status was not determined by simply summing raw scores across dimensions because the dimensions have different numbers of indicators and therefore different maximum scores. Instead, scores for the four quantitatively discriminating dimensions, function, product, production process, and linkages, were normalized by dividing each dimension score by its maximum possible score and multiplying by 100. The overall capability index was then calculated as the arithmetic mean of the four normalized dimension scores, thereby assigning equal analytical weight to each dimension.

The following thresholds were used for the overall capability index: below 50 = low; 50–59.99 = lower-medium; 60–69.99 = medium; 70–79.99 = upper-medium; and 80 or above = high. No separate "very high" category was introduced because such a category had not been theoretically or empirically defined in the original scoring framework.

The end-market dimension requires special treatment. Because all ten firms received the maximum numerical score of six, the indicator had zero variance and therefore could not discriminate between firms in the quantitative aggregation. Accordingly, the end-market score is reported descriptively but excluded from the composite index. Its substantive meaning, particularly the distinction between domestic market strength and international market access, is examined using the qualitative interview evidence.

3.4 Data Analysis Method

Qualitative interview data were analyzed using thematic analysis. MAXQDA was used to organize, code, retrieve, and compare interview segments across firms. The analysis followed a systematic thematic-analysis procedure consisting of six stages: familiarization with the data, generation of initial codes, searching for candidate themes, reviewing themes, defining and naming themes, and producing the final analytical narrative (Braun & Clarke, 2006).

The coding process was both deductive and inductive. The five capability dimensions provided an initial analytical structure, while additional codes and subthemes were generated from the interview data when participants identified issues not adequately captured by the predefined framework. Particular attention was given to differences between domestic and international market relationships, inter-firm collaboration, institutional relationships, workforce capabilities, technology acquisition, and external constraints such as sanctions, exchange-rate volatility, and import restrictions.

To enhance the credibility of the qualitative findings, three complementary procedures were employed. First, data triangulation was achieved by interviewing managers occupying different organizational positions, including CEOs, production managers, quality managers, and export managers. Second, member checking was used to clarify the interpretation of key statements with selected interviewees. Third, peer review was used to examine the coherence between codes, themes, and the final interpretation (Lincoln & Guba, 1985).

The qualitative findings were subsequently integrated with the quantitative capability scores. Quantitative scores were used to identify capability profiles and differences across firms, while qualitative evidence was used to explain the mechanisms underlying these differences and to interpret dimensions that could not adequately discriminate between firms quantitatively.

Table 3. Main Themes and Subthemes Identified from the Qualitative Interviews

Main theme	Subthemes	Illustrative analytical meaning
Production capability	Quality control; certification; machinery; delivery reliability	Strong accumulated production routines but persistent external disruptions
Product capability	Product variety; complexity; product differentiation	Moderate product complexity with relatively high variety
Functional capability	Own-brand development; branding; design; market coordination	Stronger downstream functions among established firms
Domestic market capability	Chain stores; domestic channels; brand recognition	Expansion of domestic market presence
International market capability	Export continuity; buyer stability; market diversification	Weak and unstable international relationships
Inter-firm linkages	Supplier relations; joint purchasing; joint R&D	Limited horizontal cooperation
Institutional linkages	Government relations; industry associations; customs	Weak institutional coordination
Learning and upgrading constraints	Sanctions; exchange-rate volatility; training; R&D	External constraints limit capability conversion into upgrading

4. Findings

4.1 General Characteristics of the Studied Firms

Table (4) summarizes the key characteristics of the 10 studied firms. All firms were established between 1956 and 1995 (Iranian calendar years 1335 to 1374) and all have export experience (though often intermittent and unstable). The dominant function of all firms is "turnkey"; meaning they are responsible for input supply, design, production, branding, and distribution. Annual production capacity of firms ranges from 10,000 to 50,000 tons, and number of employees ranges from 277 to 1,500. Most firms have dedicated retail networks, online channel, and direct sales. Interestingly, all firms in the last 5 years (despite the Covid crisis and reduced purchasing power) have experienced growth in capacity and workforce, which according to interviewees is mainly due to reduced presence of foreign brands due to exchange rate jumps and import bans.

Table 4: General Characteristics of Studied Confectionery and Chocolate Manufacturing Firms

Firm	Year Est.	Function	Main Products	Capacity (tons)	Employees	No. of Brands	Export Experience
A	1974	Turnkey	Chocolate, cake, biscuit, gum, snack	46,700	756	10	Yes
B	1956	Turnkey	Biscuit, cake, chocolate, wafer	50,000	972	7	Yes
C	1959	Turnkey	cheese puff, biscuit, gum, chocolate	30,000	1,242	8	Yes
D	1962	Turnkey	Chocolate, gaz, dragee, gum	15,000	560	8	Yes
E	1959	Turnkey	Biscuit, pofak, toffee	40,000	349	5	Yes
F	1961	Turnkey	Biscuit, wafer, cake, cereal	10,000	277	3	Yes
G	1979	Turnkey	Chocolate, cotton candy, jelly, wafer	10,000	600	2	Yes
H	1995	Turnkey	Chocolate, toffee, biscuit, cake mix	30,000	1,500	2	Yes
I	1965	Turnkey	Cake, chocolate, biscuit, wafer	50,000	1,100	22	Yes
J	1988	Turnkey	Chocolate, dragee, licorice, jelly	25,000	500	5	Yes

Source: Research findings.

4-2. Assessment of Firms' Technological Capabilities

Table (5) shows the disaggregated scores of each firm across the five technological capability dimensions. Analysis of findings indicates:

"End-market capability": The end-market dimension requires a cautious interpretation. All ten firms received the maximum quantitative score of six. Although this indicates that the firms have relatively broad and established market access within the measurement criteria used in the questionnaire, the absence of variation means that the indicator cannot distinguish firms statistically or contribute meaningfully to the ranking of their overall technological capabilities.

More importantly, the qualitative interviews reveal a substantial distinction between domestic market strength and international market capability. The firms generally reported strong domestic brand recognition, access to multiple domestic sales channels, and growing relationships with modern retail and chain-store networks. However, international buyer relationships were considerably less stable. Managers reported temporary export relationships, difficulties in transferring export proceeds, sanctions-related constraints, exchange-rate volatility, and instability in input prices as factors that interrupt or weaken international commercial relationships.

Accordingly, the high numerical end-market score should not be interpreted as evidence of strong global market capability. Rather, it reflects the strength of domestic market access within the original measurement structure. The qualitative evidence suggests that international market diversification, buyer stability, and continuity of export relationships remain important upgrading gaps.

"Medium dimensions": "Product" capability in 8 firms was upper-medium (score 5 out of 6) and in 2 firms (F and I) medium (score 4 out of 6). Product complexity level was assessed as "medium" in all firms, while product variety was mostly "high" (11 products or more). Although this high variety indicates flexibility from a technological capability perspective, someinterviewees warned that "excessive variety with limited scale" can lead to lower productivity through lack of focus on flagship products. "Production process" capability also had a relatively balanced distribution: three firms (A, G, H) scored high (8-9), six firms medium (6-7), and one firm (F) low (4). Notable is that despite advanced quality control systems and multiplecertifications (8 firms had more than 6 standard certificates), "on-time delivery" remains aserious challenge. Six firms acknowledged "sometimes" (2-4% of orders) and one firm "often" (more than 5%) face delivery delays. Interviewees cited factors outside the firm's control (power cuts, input shortages, customs and currency problems) as the main causes of delays.

"Weak dimensions": "Linkages" capability in 4 firms was medium (score 6-7 out of 9), in 4 firms high (8-9), and in 2 firms (F and I) low (5). But what remains hidden behind the average scores is "severe inequality within the components of linkages". In most firms, "linkages with local suppliers" (especially after the exchange rate jump and import restrictions) have strengthened, but "relations with government institutions" were assessed as weak in all firms.One CEO stated: "Unfortunately, the government has no understanding of the industry'sproblems… no financial support, no customs facilitation, no technical advice. Our onlyinteraction with the government is through paying taxes and duties." Also, "linkages with other confectionery and chocolate firms" are at a low level. Although the industry association hasbecome more active in recent years, effective and continuous inter-firm collaborations (especially in joint R&D, collective marketing, or group purchasing of inputs) have not materialized.

"Overall score": Based on the combination of the five scores, the status of firms' technological capabilities is as follows: 2 firms "high" (A, G), 4 firms "upper-medium" (B, C, E, J), 2 firms "medium" (D, I), 1 firm "lower-medium" (F), and 1 firm "very high" (H). The dispersion of scores indicates that technological capability in the Iranian confectionery and chocolate industry is not homogeneous, and a significant gap exists between leading firms (e.g., H with continuous export experience and collaboration with international brands) and firms with averageperformance.

Table 5: Technological Capability Scores of Confectionery and Chocolate Manufacturers Based on the AFRICP Model

Firm	Function	Product	Production Process	End Market*	Linkages	Overall capability
A	4 (High)	5 (Medium)	9 (High)	6 (High)	9 (High)	High
B	3 (Medium)	5 (Medium)	7 (Medium)	6 (High)	7 (Medium)	Upper-medium
C	3 (Medium)	5 (Medium)	7 (Medium)	6 (High)	9 (High)	High
D	3 (Medium)	5 (Medium)	7 (Medium)	6 (High)	6 (Medium)	Upper-medium
E	3 (Medium)	5 (Medium)	7 (Medium)	6 (High)	8 (High)	High
F	3 (Medium)	4 (Medium)	4 (Low)	6 (High)	5 (Low)	Medium
G	3 (Medium)	5 (Medium)	9 (High)	6 (High)	9 (High)	High
H	3 (Medium)	5 (Medium)	9 (High)	6 (High)	9 (High)	High
I	3 (Medium)	4 (Medium)	6 (Medium)	6 (High)	5 (Low)	Medium
J	3 (Medium)	5 (Medium)	7 (Medium)	6 (High)	7 (Medium)	Upper-medium

* End-market score is reported descriptively and is not included in the composite overall capability index because all firms received the same score.

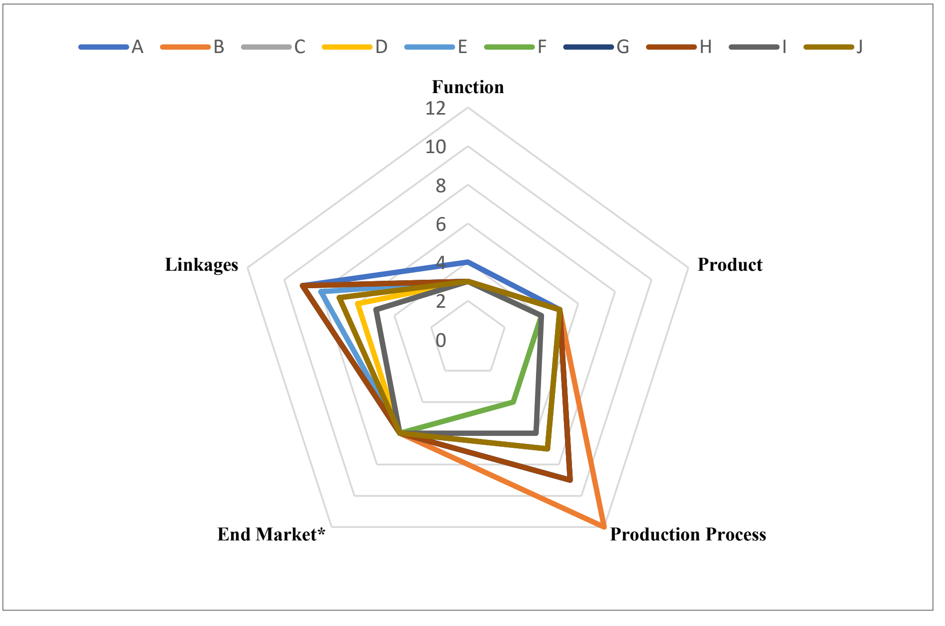

Figure 1. Technological Capability Profiles across the Studied Firms

The revised aggregation procedure produces a more internally consistent classification of the ten firms. Firm A remains in the high-capability category because of its strong performance in production processes and linkages, combined with a relatively advanced functional position. Firms C, E, G, and H also fall into the high-capability category. Firms B, D, and J are classified as upper-medium, while firms F and I are classified as medium. Importantly, firms G and H receive exactly the same classification because their observed dimension scores are identical. No "very high" category is used because such a category was not defined in the original measurement framework.

The results therefore indicate that technological capability is heterogeneous across the sample, but the distribution differs from the original classification. The strongest capabilities are concentrated in production processes and, for some firms, inter-organizational linkages. By contrast, functional depth and especially the ability to convert accumulated production capabilities into stable international market relationships remain important areas for upgrading.

4-3. Structural and Environmental Analysis of the Industry

The qualitative evidence was further interpreted through the complementary lenses of PESTEL and Porter's Diamond. These frameworks were not used as independent quantitative measurement models; rather, they were employed to organize the external factors reported by interviewees and to explain why firm-level technological capabilities have not always translated into sustained competitiveness.

From a PESTEL perspective, political and institutional factors, including international sanctions, restrictions on financial transfers, import regulations, and changes in trade policy, were repeatedly identified as constraints on international transactions and technology acquisition. Economic factors, particularly exchange-rate volatility, inflationary pressures, and fluctuations in input prices, affect both production planning and the continuity of export relationships. Technological factors show a mixed pattern: leading firms have invested in modern machinery, quality-control systems, and certifications, but investment in formal R&D remains limited. Social and human-capital factors are characterized by the coexistence of experienced technical personnel and gaps in advanced managerial, digital, and specialized skills (The evidence does not support a general conclusion that the industry suffers from a uniformly low-skilled workforce. Rather, the interviews indicate an uneven distribution of skills. The industry benefits from experienced engineers, technicians, and production personnel, particularly in established firms, while gaps remain in advanced technical skills, digital capabilities, specialized R&D competencies, international marketing, and managerial capabilities required for global market development. Thus, the principal issue is better characterized as a gap in the depth and breadth of advanced capabilities rather than a general lack of workforce skills.). Legal and regulatory uncertainty, particularly in customs and foreign-exchange procedures, further increases transaction costs.

Porter's Diamond provides a complementary interpretation. Factor conditions are supported by an established industrial base, experienced firms, and accumulated production knowledge, but weaknesses remain in advanced skills, R&D intensity, and access to specialized technological inputs. Demand conditions are relatively favorable in the domestic market because of strong brand recognition and the expansion of modern retail channels, but domestic demand alone is insufficient to generate sustained international competitiveness. Related and supporting industries remain fragmented, particularly with regard to inter-firm collaboration, joint R&D, collective purchasing, and institutional coordination. Finally, firm strategy, structure, and rivalry have encouraged investment in production and branding capabilities, but external constraints have limited the ability of firms to translate these capabilities into diversified international market positions.

Taken together, the two frameworks indicate that the principal competitiveness challenge is not the absence of production capability per se, but the weak conversion of firm-level capabilities into sustained learning, coordination, innovation, and international market access.

5. Discussion and Conclusion

5-1. Interpretation of Findings in Light of the Literature

The findings provide a more differentiated picture of technological capability in the Iranian confectionery and chocolate industry than a simple high-versus-low classification would suggest. The firms have accumulated relatively strong capabilities in production processes and product variety, reflecting learning through repeated production, investment in quality-management systems, acquisition and adaptation of machinery, and exposure to demanding domestic and export markets. This pattern is consistent with the technological-capability literature, which emphasizes that firms in developing economies often accumulate production capabilities before achieving more advanced functional, market, and innovation capabilities (Lall, 1992; Morrison et al., 2008).

However, the findings also demonstrate that production capability does not automatically translate into international upgrading. The firms examined in this study have relatively strong domestic market access, but the qualitative evidence indicates that international buyer relationships remain unstable. This distinction is important because market access and technological capability are mutually reinforcing only when market relationships generate sustained learning, information exchange, and opportunities for upgrading. In the Iranian context, sanctions, exchange-rate volatility, restrictions on financial transfers, and trade-policy uncertainty interrupt these learning mechanisms.

The findings concerning linkages are particularly important. While some firms have developed stronger relationships with local suppliers, horizontal collaboration among manufacturers and institutional relations with government agencies remain weak. This supports the broader literature emphasizing the role of inter-firm and institutional linkages in knowledge diffusion and technological upgrading (Morrison et al., 2008). The problem is therefore not simply a shortage of technological resources within individual firms; it is also a coordination problem involving firms, suppliers, industry associations, knowledge institutions, and public agencies.

The findings are also consistent with the global value chain literature, which distinguishes process, product, functional, and market upgrading (Humphrey & Schmitz, 2002; Gereffi et al., 2005). The Iranian firms appear to have made greater progress in process and product capabilities than in international market and linkage capabilities. Consequently, the central upgrading challenge is to convert accumulated production knowledge into more diversified markets, stronger relational capabilities, and sustained learning.

5-2. Upgrading Paths: Opportunities and Constraints

According to the findings, the Iranian confectionery and chocolate industry appears to be at an **"important turning point"**. On one hand, significant technological capabilities (especially in production processes, quality control systems, and product variety) have been accumulated in recent years. On the other hand, constraints in accessing global markets (due to sanctions and structural barriers) and weak institutional linkages prevent full exploitation of these capabilities. In such circumstances, three upgrading paths are conceivable:

"Path One: Deepening in regional and neighboring markets". Instead of focusing on distant European and American markets (which require stringent standards and stable business processe), Iranian firms can target regional markets such as Iraq, Afghanistan, Pakistan, Persian Gulf states, and the Eurasian market. These markets are culturally and taste-wise closer to Iran, with lower entry barriers. The experience of some studied firms (e.g., C and H) shows that continuous exports to Iraq and Afghanistan have been possible despite sanctions. Supportive policies such as customs process facilitation, creation of dedicated export lines, and participation in regional fairs can strengthen this path.

"Path Two: Developing own brands and chain stores in the domestic market". Given the reduced presence of foreign brands (due to exchange rate jumps and import restrictions), a historic opportunity has arisen for domestic brands to increase their market share and consolidate brand identity. This path is profitable in the short term, but in the long term cannot substitute for presence in global markets. Therefore, it should be considered as a temporary and complementary strategy.

Path Three: Collaborating with multinational companies through contractual models (OEM/ODM)". Although sanctions are the main barrier to this path, some interviewees indicated that companies of Russian, Chinese, and Indian nationality are willing to collaborate with Iranian firms (due to low final cost and acceptable quality). Perhaps through the formation of export consortia or specialized trading companies, these negotiations could be facilitated.

Ultimately, this research shows that upgrading the Iranian confectionery and chocolate industry is a "multilevel" issue requiring coordinated interventions at the macro level (exchange rate and trade policy), the sectoral level (supply chain development, standards, R&D), and the firm level (marketing capabilities, branding, linkages). Table 6 summarizes the most important proposed policies based on the research findings.

Table 6: Summary of Proposed Policies at Macro, Sectoral, and Firm Levels

Level	Capability problem	Recommended intervention	Expected upgrading outcome
Macro	Financial and trade uncertainty	Facilitate export-proceeds transfer and reduce foreign-exchange uncertainty	Greater continuity of international transactions
Macro	Sanctions and transaction barriers	Develop alternative financial and trade mechanisms within the applicable regulatory framework	Lower transaction costs
Industry	Weak inter-firm linkages	Establish export consortia, joint purchasing and joint R&D platforms	Stronger collective capabilities
Industry	Limited advanced skills	Industry-specific technical and managerial training	Deeper human capabilities
Industry	Weak international market intelligence	Shared export-market intelligence and buyer databases	Market diversification
Industry	Limited R&D	Establish competitive industry R&D programs involving firms and research institutions	Product and process upgrading
Firm	Strong production but weaker market upgrading	Invest in international marketing, branding and customer relationship capabilities	Functional and market upgrading
Firm	Product variety without sufficient focus	Develop high-value-added and differentiated product portfolios	Product upgrading
Firm	Weak institutional relationships	Strengthen engagement with industry associations and relevant public agencies	Institutional upgrading

5-3. Limitations and Directions for Future Research

Several limitations should be considered when interpreting the findings. First, the empirical sample consists of ten leading firms and therefore does not represent the full population of Iranian confectionery and chocolate manufacturers, particularly small and medium-sized firms without export experience. Second, capability scores were partly based on managerial assessments rather than direct observation of production processes, independent audits, or access to firm-level financial records. Although interviews with managers occupying different organizational positions and member checking were used to reduce interpretive bias, self-reported assessment remains a potential source of measurement error.

Third, the end-market indicator displayed zero variance across the ten firms. This limitation reduces its usefulness as a quantitative discriminator and indicates the need for a more refined measurement model that separately captures domestic market capability, export-market diversification, buyer stability, and international customer relationships. Future studies should therefore develop and validate a multidimensional market-capability scale rather than relying on a single aggregate indicator.

Fourth, the research captures a specific period characterized by considerable exchange-rate, trade-policy, and sanctions-related uncertainty. Longitudinal research would therefore be valuable for examining how technological capabilities evolve in response to changes in the external environment.

Future research should extend the present study by including a larger and more representative sample, developing a validated measurement scale for technological capabilities in food-processing industries, comparing Iranian firms with regional competitors, and examining the longitudinal relationship between technological learning, market access, and upgrading.

5-4. Final Conclusion

This study examined the technological capabilities of ten leading Iranian confectionery and chocolate manufacturers using a capability-based framework adapted to the characteristics of the industry. The results indicate that the industry has accumulated meaningful capabilities in production processes and product development. These capabilities are reflected in quality-management systems, production technologies, certifications, product variety, and accumulated operational experience.

At the same time, the analysis shows that capability accumulation remains uneven. The principal weaknesses are not necessarily located in basic production capabilities but in the mechanisms through which firms transform these capabilities into sustained upgrading. Inter-firm collaboration, institutional linkages, advanced R&D capabilities, and stable international market relationships remain insufficiently developed.

An important methodological finding is that the original end-market indicator did not discriminate among the firms because all ten received the maximum score. The result should therefore not be interpreted as evidence that firms possess equally strong global market capabilities. Instead, the qualitative evidence indicates a clear distinction between relatively strong domestic market access and more fragile international market relationships. This distinction highlights the importance of separating domestic market strength from export-market capability in future measurement instruments.

Overall, the evidence suggests that the industry's strategic challenge is best described as a transition from production capability accumulation toward capability conversion and systemic upgrading. At the firm level, this requires deeper investment in product differentiation, R&D, international marketing, and organizational learning. At the industry level, stronger supplier networks, joint R&D, export consortia, and collective market intelligence are required. At the policy level, predictable trade and foreign-exchange arrangements, facilitation of financial transactions, support for international certification, workforce development, and mechanisms for inter-organizational learning are necessary.

The central implication is therefore that Iranian confectionery and chocolate manufacturers largely possess the ability to produce competitively, but their capacity to learn collectively, sustain international relationships, and convert production capabilities into diversified global-market positions remains comparatively limited. Industrial policy should consequently shift from narrowly supporting production toward facilitating capability accumulation, coordination, learning, and international market upgrading.

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Development of Chitosan/Nanohydroxyapatite particles/$AgNO_3$/vancomycin scaffold for vancomycin delivery

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Abstract

Tissue engineering is defined by some characteristics such as biocompatibility, biodegradability, low immunogenicity, bio absorbability, nontoxicity, rejuvenation, and restoration properties. However, 3D-Scaffold are used having these characteristics with physical and chemical consideration. In this study a three-dimension scaffold was synthesized containing chitosan, Nanohydroxyapatite as an osteoconductive material, AgNO3 as an antiviral as well as anticancer therapeutic agent, and vancomycin that is considered for treating a number of bacterial infections. The behavior of the synthesized scaffold as a drug release material was investigated. Scaffolds were synthesized by freeze drying technique and characterized by scanning electron microscopy (SEM), Fourier transform infra-red spectroscopy, antibiogram method for In vitro tests and UV absorption device for evaluating the drug release behavior. It was found that drug delivery of scaffolds depended on the HA and AgNO3 content whereas less HA resulted in more drug release and AgNO3 postponed the vancomycin release after about 1000 h examination. Moreover, the diagram of drug delivery system demonstrated the predictable release manner of vancomycin in scaffolds. Results of drug delivery tests indicated that AgNO3 have controllable efficacy on sustain delivery and with surpassing percentage of Ag, release of vancomycin have been extended more than 1 month with 60% delivery of drug.

Keywords: Tissue engineering; Drug delivery system; Scaffold; Hydroxyapatite; Chitosan.

چکیده

این پژوهش به سنتز و ارزیابی داربست سه‌بعدی نوین در مهندسی بافت با روش خشک‌کردن انجمادی می‌پردازد که حوزه‌ای پیشران و با ارزش افزوده بالا در صنایع زیست‌پزشکی و بیومواد معدنی به حساب می‌آید. ماتریس این داربست از کیتوسان، ماده رسانای استخوانی نانوهیدروکسی‌آپاتیت (nHA)، نیترات نقره ($AgNO_3$) به‌عنوان عامل ضدسرطان و ضدویروس و داروی وانکومایسین جهت مقابله با عفونت‌های باکتریایی تشکیل شده است. در این مسیر ساختار و کارایی محصول با تکنیک‌های SEM، FTIR، آزمون‌های آنتی‌بیوگرام و طیف‌سنجی UV برای بررسی رفتار رهایش دارو سنجیده شد. از منظر فنی و اقتصادی، نتایج نشان‌دهنده قابلیت بالای تجاری‌سازی فرمولاسیون به‌دلیل دستیابی به رهایش کنترل‌شده و پایدار است؛ عاملی که هزینه‌های مراقبت درمانی و ریسک شکست پیوند را کاهش می‌دهد. غلظت ترکیبات معدنی و دارویی نقشی تعیین‌کننده دارد: کاهش nHA منجر به افزایش شدت رهایش دارو شده، درحالی‌که افزایش $AgNO_3$ آزادسازی وانکومایسین را تعدیل و تا بیش از ۱۰۰۰ ساعت به تأخیر می‌اندازد. در نمونه‌های دارای درصد نقره بالاتر، آزادسازی دارو روندی کاملاً قابل‌پیش‌بینی و پایدار یافته و پس از گذشت بیش از یک ماه به ۶۰ درصد کل بارگیری رسید. تلفیق مواد معدنی فرآوری‌شده (هیدروکسی‌آپاتیت و نقره) با پلیمرهای زیستی، این محصول را به گزینه‌ای رقابتی و استراتژیک در صنایع نوین ترمیم استخوان و سیستم‌های هوشمند رهایش دارو بدل می‌سازد.

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1. Introduction

Due to the importance of tissue engineering, scientists highly focused on this filed of science and technology in recent years [Khademhosseini and Langer, 2016]. However, recent research is devoted to bone tissue engineering and in particular to 3D porous scaffold by which specific living cells and drugs are released to a tissue in the period of regeneration or replacement [Langer and Vacanti, 2016]. Clearance of biopharmaceuticals such as nucleic acids, peptides, and amino acid are often confined by feeble stability and quickly out from the body. These challenges, are developed novel drug delivery systems that overcome sustained delivery obstacles with cooperation pharmaceutical sciences. When a pharmaceutical agent is encapsulated within, or attached to, a polymer or lipid, drug safety and efficacy can be greatly improved and new therapies are possible [Langer, 1998].

Despite of the research and improvement of methodologies and materials in the field of polymer drug delivery, still efforts are focused on this subject. Polymer carriers that are accompanied with therapy agents provide adequate condition for temporary controlling and release of a drug by dissolution or degradation of the carrier.

Suitable selection of polymer affects the performance of the drug delivery system, as the polymer influences directly on efficacy and efficiency of the rate and duration of release. On the other hand, some ceramics such as hydroxyapatite (HA) particles has been the subject of interest as a drug carrier due to its osteoconductivity and biocompatibility characteristics [Hoseinzadeh et al., 2016]. No antibacterial activity of HA particles has been reported [Fragal et al., 2016, Kavasi et al., 2017].

Silver ions have been used in medical devices, pharmaceutical products in the treatment of various bacterial infections. Alliance HAp, Ag + has been created the situation to utilize properties of two elements [Liu and Man, 2017]. Sustained drug delivery of vancomycin was depended on the ratio of scaffold materials. In addition, mechanical and physical properties must be considered for creation optimized scaffold.

Drug delivery systems (DDS) have been expanded to enhance bone ingrowth and regeneration in the treatment of bone defects. Researches have been demonstrated the main role of porosity, pore size and interconnected pores in scaffold design and significant effect on tissue engineering and DDS application [Ginebra et al, 2006]. Drug delivery systems have inherent advantages and limitations. Drug release from any carrier is determined by a complex interaction between the drug and polymer in environmental/in vivo conditions. Depending on the drug release behavior, drug delivery devices have been classified into three major classes: diffusion controlled, chemical processes, controlled, and externally or electronically controlled.

Chitosan is a natural polysaccharide and is considered the largest biomaterial after cellulose in terms of distribution and utilization and is significant choice for drug delivery system as scaffold for repair of bone defects, bone marrow-derived, cartilage healing, bone regeneration [Park, 2017]. Chitosan has many physical, chemical and biological properties referred by its functional groups (amino NH2 and hydroxyl OH). Researchers have utilized a nanoparticle-embedded chitosan sponge for Topical and Local Administration of Chemotherapeutic Agent [Goldberg et al., 2014].

Other researchers investigated the enhancing cell penetration and proliferation in chitosan hydrogels for tissue engineering applications and fabrication of porous chitosan scaffolds for soft tissue engineering [Ji et al., 2011].

In recent years comprehensive studies have been carried on characteristics of chitosan in the drug delivery areas such as antibiotic drug with using chitosan nanoparticles [Zhao et al. 2013], enhance antitumor efficiency by targeted drug delivery via CD44 [Wang et al., 2017]. Hydrophobic–hydrophilic interactions between drug-polymer and drug-release medium may also effect on the release kinetics [Bose and Tarafder, 2012]. Chitosan/nano hydroxyapatite composites have been more application for tissue engineering, because of its ability to impel a good proliferative response in osteoblasts [Lee et al., 2014].

Silver is an appropriate choice for targeting treatment in cancer therapy in drug delivery fields. Silver nanoparticles (AgNPs), as effective antimicrobial agents with low toxicity, have been studied widespread and used in various fields [Sharma et al., 2009]. Chitosan interacts with many metals, including Ag^+, Cu^{2+}, Fe^{3+} and Zn^{2+}. Due to the existence of amine (NH-) and hydroxyl (OH-) groups, the chitosan chains easily bind to the Ag^+ , the CH/Ag beads show a smooth and firm surface which becomes smoother with the increase in the AgNPs content because interfacial interactions and intermolecular cross linkers [Freire et al., 2016]. Antimicrobial and anticancer activities have been showed in the porous chitosan-alginate biosynthesized silver nanoparticles, and use of chitosan/silver as a novel carrier [Wakure et al., 2016].

Previous studies in XRD patterns have been indicated that Ag is incorporated within the HA, combination of HAp and Ag^+ ions is the best way for ensuring antibacterial achievement with delivery of Ag ions directly to the implant tissue interface [Ciobanu, 2013].

Vancomycin ($C_{66}H_{75}Cl_2N_9O_{24}$) have been applied in several applications such as chitosan and calcium sulfate scaffold [Doty et al., 2014]. For more than 4 decades, vancomycin has been the antibiotic of choice for methicillin-resistant Staphylococcus aureus (MRSA) infections. Due to damage to vital organs such as heart and kidneys via systemic administration, VCM is preferred to be used locally special in the form of scaffold. Beginning in the early 1980s, a dramatic increase in vancomycin use occurred, with a >100fold increase occurring over the next 2 decade [Kirst et al., 1998].

The antibacterial activities of composite scaffolds were investigated by a zone inhibition method [Yang et al., 2017]. Scaffold samples were cut in disk shape with 1.5cm in height and 1.4 cm in diameter. Bacillus cereus (B. cereus) ATCC-12228 and staphylococcus aureus (S. aureus) ATCC-47077 as Gram + bacteria and Escherichia coli (E. coli) ATCC-25922 as Gram– were used for antibacterial studies [Numao et al., 1997]. Using the spread plate method, different plates were inoculated with 1 mL of bacterial suspension containing approximately 10cfu/mL of each bacterium. The scaffolds were placed on the inoculated plates and were incubated at 37°C for 24 hours. Zones of inhibition were distinguished by measuring the clear area formed surrounding each scaffold

2. Materials and Research Procedures

2.1 Reagents and media

Chitosan powder with minimum 85% deacetylated with Mw of 310,000 g/mol, synthetic hydroxyapatite nano-powder with purity of more than 97% purchased form Sigma-Aldrich, acetic acid 96% with a density of 1.06 g/cm3, vancomycin (chemscene) and AgNO3 obtained from Merck were used in this study.

Phosphate buffered saline (PBS) solution was prepared in lab with the following process for 1 liter of PBS: 8 g of NaCl (Merck) together with 0.2 g of KCl (Merck), 1.44 g of Na2HPO4 (Merck) and 0.24 g of KH2PO4 (Merck) was added to 800 ml of distilled water and then the pH was adjusted to 7.4 with HCl (Merck) and distilled water to a total volume of 1 liter. Materials were freeze-dried after which the frozen water is converted directly into the gas phase in sublimation form, which results in pore formation .This method was first utilized by Whang et al. to fabricate PLGA scaffolds [Sachlos and Czernuszka, 2003].

2.2 Preparation of scaffolds

Samples preparation has been carried out in 4 laboratory flasks separately. Three volumetric flasks the samples C1, C2, C3 were prepared according to Table (1) where acetic acid 2% (Merck 96% with a density of 1.06 g/cm3) was used as the solvent. The solutions were homogenized with the aid of magnetic rotator with 3500 rpm for 24 Hours. Control sample (sample C) was prepared without using AgNO3. Then Ag and vancomycin were added to solution in flasks and operation of mixing continued for 48 hours with the same velocity.

HA nanoparticles were added to the solutions and were mixed for 24 hours. Then the mixture was transferred into molds and were kept in freezer at a preset temperature of -50°C to solidify the solvent and induce a solid–liquid phase separation. After 12 hours, the frozen mixture was transferred into a freeze dryer. Scaffolds have kept in -50ºC condition for 3 days. Fig. 1 shows the appearance of the prepared scaffolds.

Table. 1. Ratios of components in the prepared scaffolds (wt%)

Samples	Chitosan	HA	AgNO3	Van	Acid acetic
C1	2.35	0.97	0.04	0.04	96.6
C2	3.00	0.32	0.04	0.04	96.6
C3	1.99	0.97	0.4	0.04	96.6
C	2.39	0.97	0	0.04	96.6

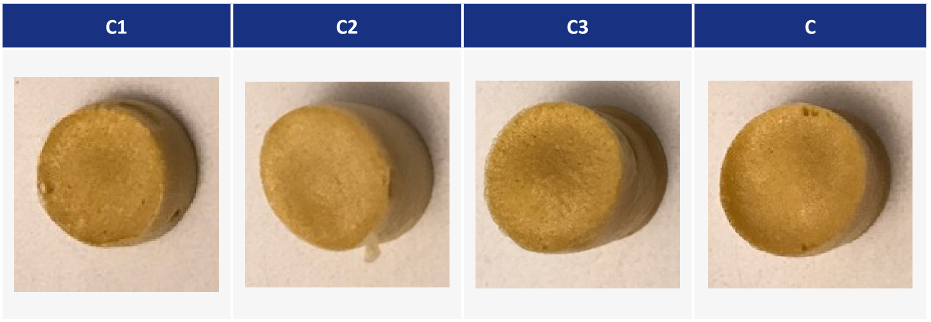

Fig. 1. Prepared samples C1, C2, C3 and C

The morphology and microstructure of the samples before and after examinations were studied using optical (Olympus) and scanning electron microscopy (SEM KYKY EM3200). The compression test was used with Instron (Model: 4505, UK) by applying load via 1 n load cell at a crosshead speed of 2 mm/min in ambient conditions. Fourier transform infrared (FTIR) spectra were obtained using a Nicolet 5-DXB FTIR spectrometer.

X-ray diffraction (XRD) is a versatile analytical method for the detection and quantitative determination of various crystalline phases. XRD data were collected via Philips PW 1710 diffract meter with Cu K□ radiation (□= 1.5406 E) and graphite monochromatic, operated at 45 kV; 30 mA and 25□C.

3. Results and Discussions

3.1 Optical analysis

Increasing the amount of Ag ions in solution change the color of the solution, and hence, the final appearance of dried sample (Fig.1). There is progressively color alternation yellow to brown when ascending Ag ions percentage indicating the change in the structure of Ag when combined with chitosan. As the concentration of silver increases, absorption peak decreases, which might probably be due to the formation of clusters, thereby, decreasing the formation of Ag ions, as described by others [Wei et al., 2009].

3.2 SEM specification

The surface morphologies of all of the scaffolds were studied by scanning electron microscopy. The pores and interconnectivity of porosities are evident from SEM images in Fig. 2. Examinations show that the pores in sample C1 were symmetrical and relatively uniform, whereas in C2 and C3 samples, pores were irregular in shape and bigger. C1 sample possesses HA three times of C2 whereas C3 possesses $AgNO_3$ ten times of C1. Fig. 2 also shows that interconnectivity of the pores is obtained which is important for scaffolds for cell growth and vascularization.

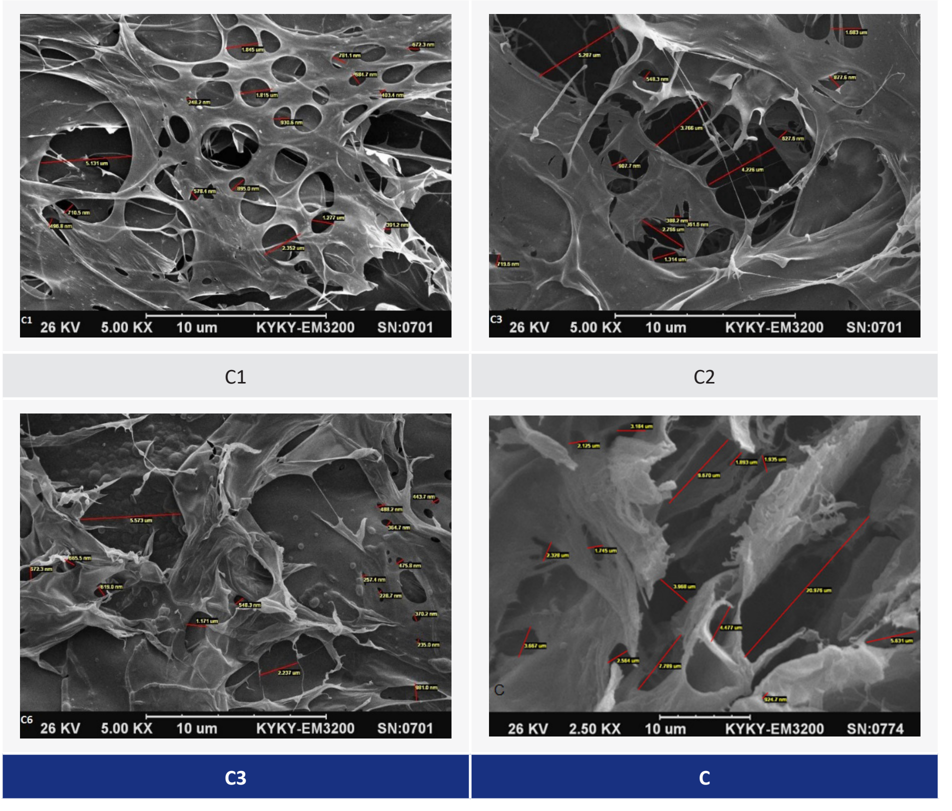

Fig. 2. Scanning electron microscopy images of prepared scaffolds.

The effect of pore size and structure is reviewed by others [Huang et al, 2025]. The porosity of the scaffolds was calculated by measuring their dimension and weight. The average pore size was calculated from scanning electron microscopy images. A typical porosity of 70% in addition a pore diameter of at least 100 μm is known to be compulsory for cell penetration and a proper vascularization of the ingrown tissue [Ramay, Zhang, 2004].

The total porosity (P) of scaffolds can be determined by measuring the porosity and scaffold volume. For measuring the porosity volume, the scaffold was immersed in ethanol alcohol and the absorbed weight was recorded:

$$v_{porosity} = \frac{mass\ of\ absorbed\ alcohol}{\rho_{ethanol\ alcohol}} \tag{1}$$

$$Total\ posority = \frac{v_{porosity}}{v_{scaffold}} \tag{2}$$

Where ρ scaffold is 0.789 g/cm^3. The volume of scaffold is calculated by measuring the diameter and height of the sample. The result is shown in Table (2).

Table. 2. Porosity percent in scaffolds studied

	C1	C2	C3	C
Diameter of the samples (mm)	27.96	28.2	28.6	28.04
Average height of the samples (mm)	3.7	5.17	5.1	5.18
Volume of scaffold (cm^3)	2.272	3.232	3.275	3.202
Weight of alcohol absorbed (gr)	1.36	2.06	2.01	1.79
Volume of pores (cm3)	1.72	2.61	2.55	2.27
$\Delta V/V$	76%	81%	78%	71%

Table 2 shows that increasing in HA percent caused decreasing porosity from 81% to 76%. Moreover, results showed increasing AgNO3 in C3 sample enhancing porosity from 76% to 78%. Comparison between C and C1 samples indicates that AgNO3 (0.04%) is caused to increasing porosity 71% to 76%.

In other words, pore average size and interconnected porosity in SEM images have shown that pores with 250 to 500 nm in sample C1 was changed with chitosan and AgNO3 percentage. As AgNO3 increased in C3 sample in comparison with that of C1 sample, pores size was decreased with ease of their interconnection. Moreover, comparison between C1 and C sample showed that presence of AgNO3 in scaffold would affect pore size and their interconnection.

3.3 Mechanical analysis

Compressive strength is an important mechanical parameter for porous scaffolds. Therefore, a mechanical test was performed to find out the compressive strength of the prepared scaffolds. The stress–strain curve obtained was used to determine the mechanical properties. Fig. 3 shows the results of the mechanical tests on the prepared scaffolds.

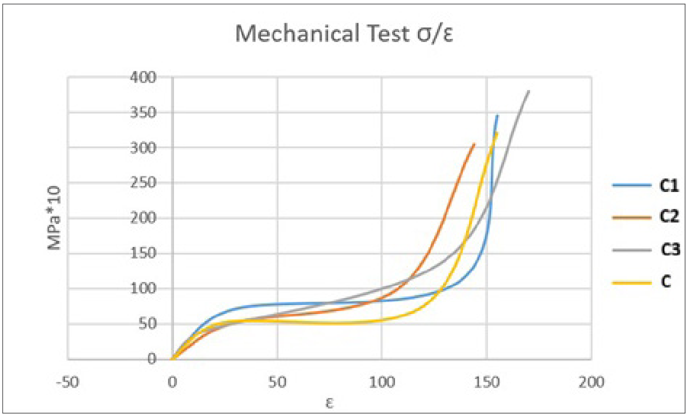

Fig. 3. Stress-strain curves of the scaffold samples.

As demonstrated in Fig. 3 maximum compressive strength for C1, C2, C3 and C was found as 10.2, 7.6, 12.2 and 5.5 MPa, respectively. The highest amount in C3 sample shows the effect of AgNO3 and HA on increasing the compressive strength. The strength of control sample without AgNO3 was less than those of C1 and C3 sample and higher than that of C2 scaffold. This shows the effect of HA as C sample possess about three times of that in C2 sample. A similar founding was reported by other researchers showing that increasing the HA led to an increase in the compressive strength. The incorporation of chitosan into scaffold resulted in decreasing of compressive strength due to the weaker interfacial bonding between chitosan and HA matrix. Li et al. compared the compressive strengths of dense scaffolds with different Chitosan/HA composite ratio and reported the maximum compressive strength to be 119.86 MPa at the chitosan/HA ratio of 30:70 [Li et al., 2005].

3.4 FTIR Spectroscopy analysis

A small amount of powder was scratched from the surface of the scaffolds, milled with KBr, and pressed into a transparent disk for analysis. FTIR spectra were gathered at a resolution of 4cm-1 and 256 scans over a range of 400 to 4000 wave numbers (cm-1), according to the reference [Liu et al., 2012].

The FTIR spectral analysis of pure chitosan shows common bands at 3436 cm-1, 2912 cm-1, 1648 cm-1, 1377 cm-1 and 1076 cm-1 that belong to the stretching vibration of OH and NH groups, CH group, amide group, COO group of carboxylic acid salt and stretching vibration of C O C in glucose unit. The FTIR spectral analysis of hydroxyapatite powder was showed 3568, 1461, 1041,570 cm-1 that were related to O-H, CO3, PO4 and Hpo4 bonds, according to the references [Lin et al., 2017, Rehman and Bonfield, 1997]. Spectral analysis of AgNO3 was illustrated 3333,1370,1029,1629 cm-1 that were reported by other research [Popovych et al., 2016, Han et al., 1998]. Some feeble pick in the range of 1000 to 1750 were occurred that related to the vancomycin in the scaffolds (Fig. 4).

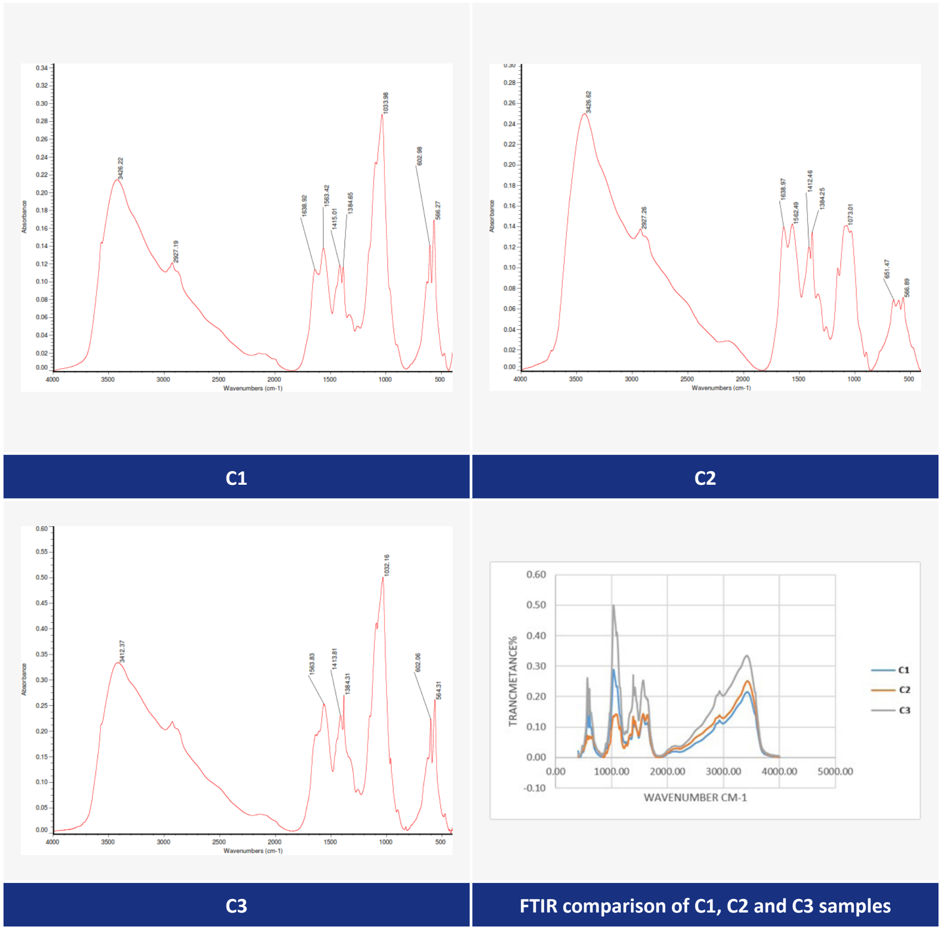

Fig. 4. FTIR results of prepared scaffolds in this study

The peaks in the range of 3000 to 3500 cm-1 represented the O-H and N-H bond that was related to HA and chitosan. In the region of 2500 to 3000 cm-1 the peak at 2927 cm-1 was related to the C-H bond in chitosan. In the range of 1000 to 1500 cm-1 the PO4 peak was detected with different intensity in C1 and C3 samples. The 566 cm-1 peak was HPO4 in all samples. The 1415 cm-1 peak was related to C-N bond that was demonstrated in all samples. N-H bond in chitosan was showed at 1638 cm-1.

3.5 XRD Analysis

The structural properties of chitosan-Ag composites were analyzed using XRD technique. Peaks of chitosan was at 2θ° of 10.5,20,22, and those of Ag at 9, 38.18, and 44.25. Hydroxyapatite was exhibited some peaks at 26, 31.5, 32.5, 33, 40, 47, 50, 54 (Fig. 5). Sharp peak at 2θ of 9° relates to AgNO3 which shows relatively high amount of this phase in sample C3. With decreasing HA in C2 sample, intensity of peaks and also crystallinity were reduced.

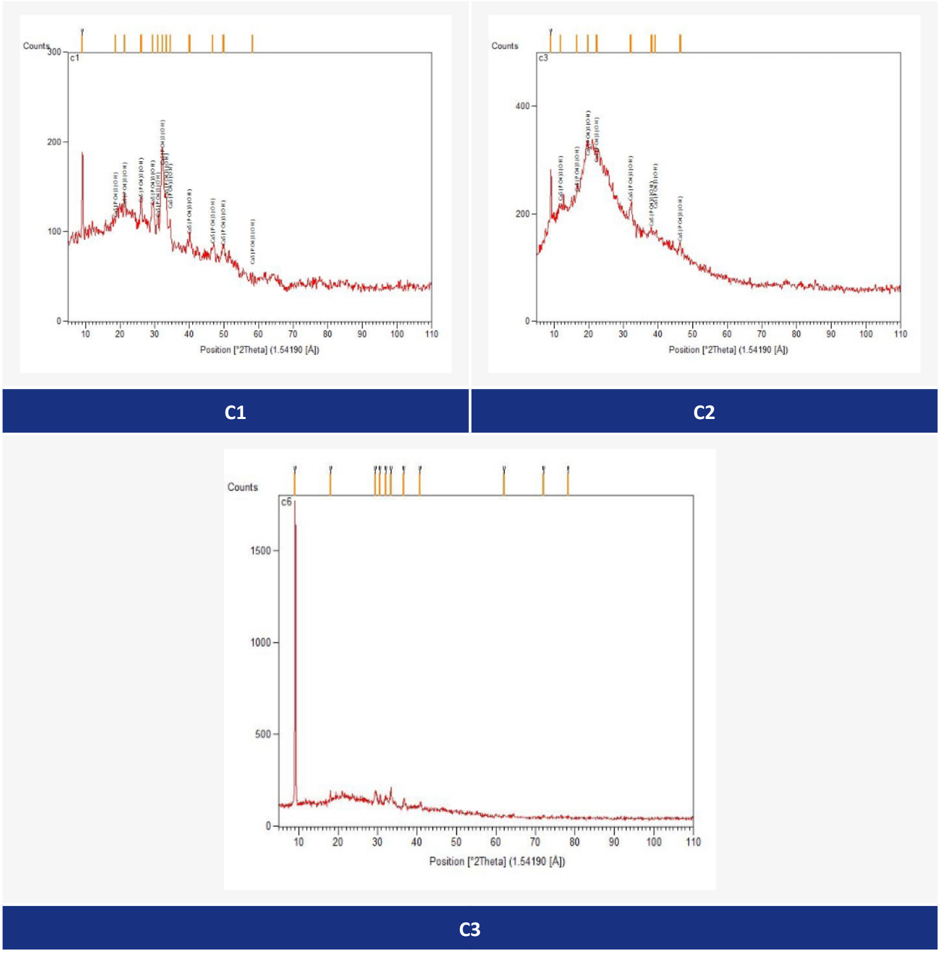

Fig. 5. XRD patterns of prepared scaffolds

3.6 Antibacterial Activity of scaffolds

The antibacterial activities of composite scaffolds were investigated by a zone inhibition method. Fig. 6 shows the appearance of the scaffolds after exposure to different bacteria.

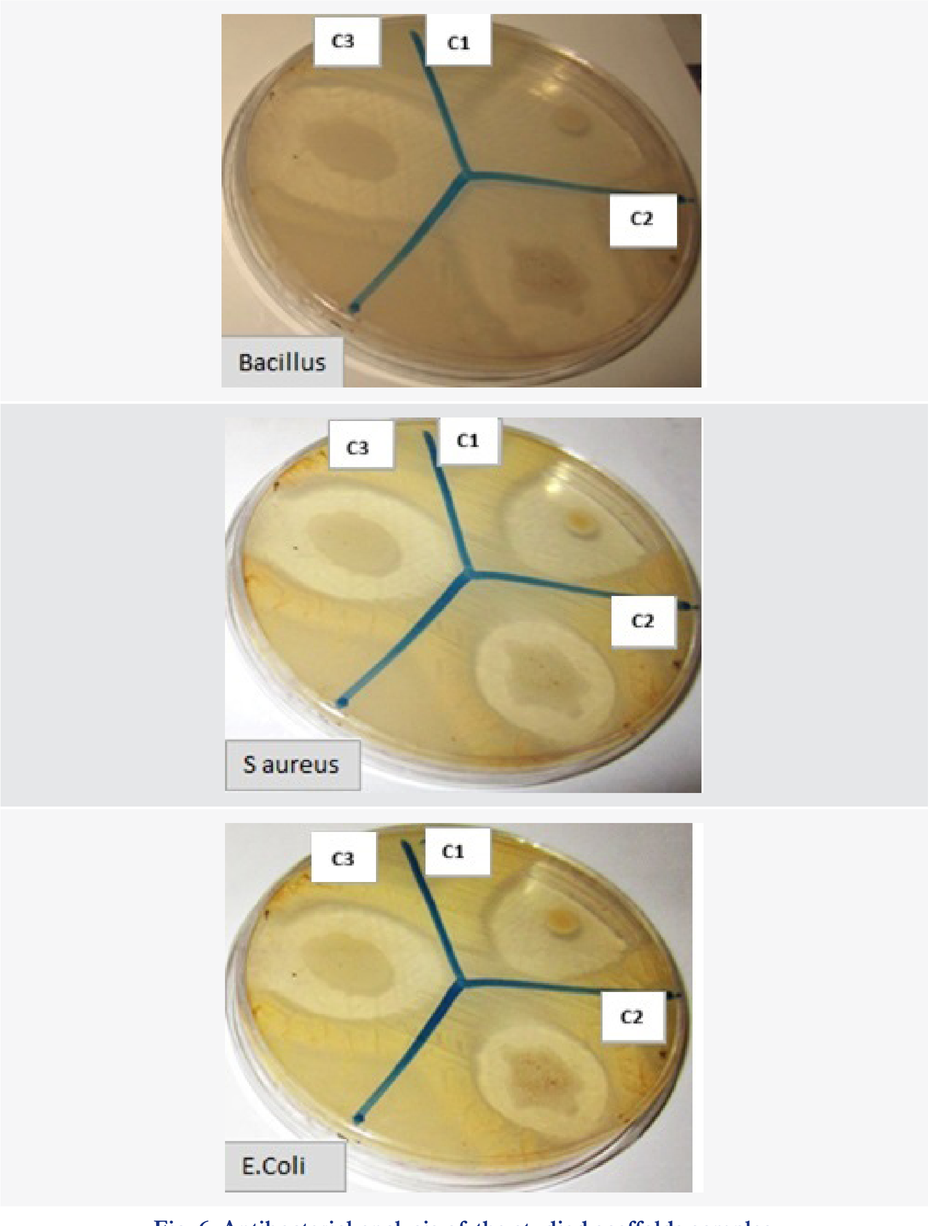

Fig. 6. Antibacterial analysis of the studied scaffolds samples

Diameter of inhibition of each scaffolds against Basillus, S aureus and E. Coli were determined and results are shown in Table 3.

Table. 3. Diameter of inhibition in antibacterial analysis (mm)

	Bacillus	S aureus	E.Coli
C1	11.3± 1.3	9.4± 1.3	8.5± 1.3
C2	7.8± 1.1	6.2± 1.4	5.9± 1.4
C3	16.7±2.5	14.5± 1.5	13.7± 1.3

Inhibition activity of scaffold samples against three different bacteria is such that C3 possesses largest diameter whereas C2 showed least diameter. Regardless of the bacteria type, increasing AgNO3 and reducing HA resulted in more antibacterial activity.

3.7 Swelling characteristics of the scaffolds

Prior to inserting in phosphate buffered saline (PBS), the weight of each scaffolds sample was recorded as *Wo*. Then, the scaffolds were immersed in the prepared PBS with pH of 7.4, at 37ºC for 24 hours. After 24 h, the scaffolds were taken out of PBS, cleansed, dried and weighed. The obtained weights of the scaffolds were recorded as *Ww*. The ratio of swelling was determined using the following equation:

$$Swelling\ ratio = {(W_w - W_0)}/{W_0}$$

Fig. 7 shows the swelling ratios of scaffold samples, which are 26, 53, 32 and 24 for C1, C2, C3 and C, respectively. From the results, it is clear that increasing AgNO3 in C3 increased the adsorption in comparison with those of C1and C samples. Moreover, reduction of HA in sample C2 increased the adsorption and hence, swelling ratio.

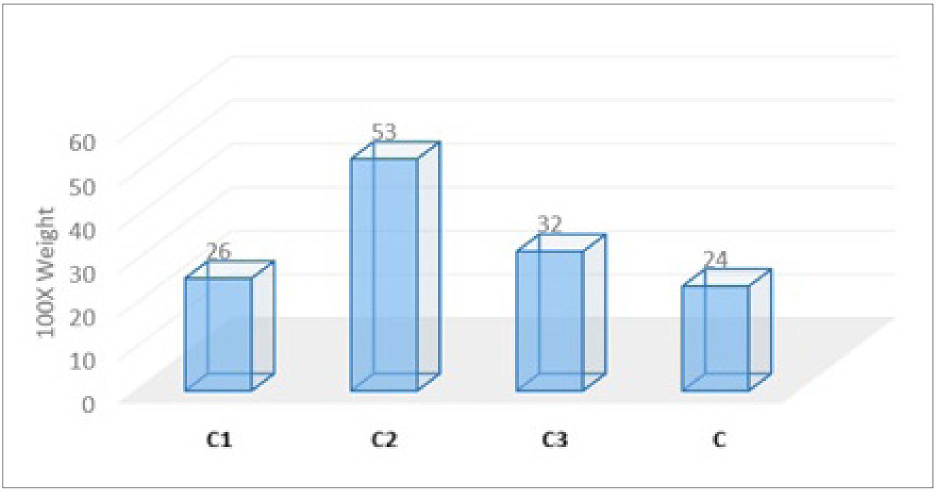

Fig. 7. Percent of PBS adsorption after 24 hours

3.8 Determination Drug release

After taking out scaffolds from freeze dryer device, the samples were prepared for drug release experiments. This test is indeed the diffusion test of drug from the scaffold. Uniform section of scaffolds was prepared and put in falcon tubes with 20 ml of phosphate buffered saline (PBS) with pH of 7.4 in a water bath at 37□C. The drug molecules entrapped in the scaffold were released in period of time in PBS environment. In interval of time of 1h, 3h, 8h the samples were taken out of falcon tube. By using UV absorption device, the amount of released drug was determined.

In order to quantify drug release, various mathematical models are proposed and used [Martнn-Camacho et al., 2023, Azadi et al., 2017, Gomes-Filho et al., 2019]. The Weibull equation can be applied to almost all kinds of dissolutions [Hirai et al., 2017]. In the case of pharmaceutical dissolution, this equation represent the mass of fraction of drug in solution and is given by [Wang et al., 2015]:

$$M = M_o \left[1 - e^{(t-{}^{T}/_{a})b}\right]$$

Where, M is the amount of drug dissolved as a function of time t, T accounts for the lag time measured as a result of the dissolution process, parameter 'a' denotes a scale parameter that describes the time dependence. While 'b' describes the shape of the dissolution curve advancement it is equal to 1 where the shape of the curve is similar exactly to the shape of an exponential profile.

Results of vancomycin release from the studied scaffolds are given in Fig. 8. As it is clear from figure, illustrated that with increasing AgNO3 in C3 sample, stability and sustainability of delivery enhanced, such that after 1000 hours, only 42% of drug was released in C3 sample whereas in C2 sample 60% of vancomycin was released. In comparison between C1 and C2 it is was found that less HA in scaffold resulted in higher drug release from about 50% in C1 to 60% in C2 after 1000 hours.

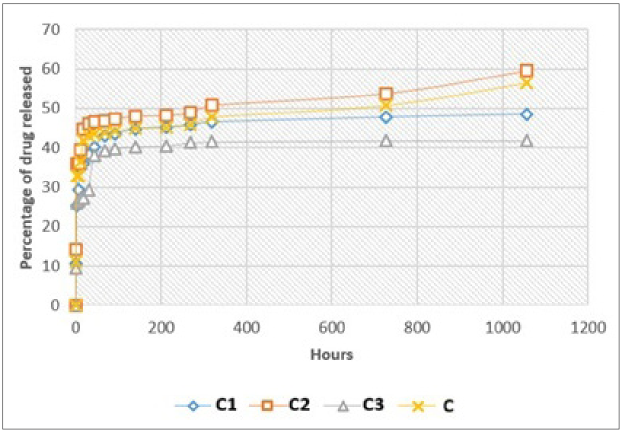

Fig. 8. Release of vancomycin from studied scaffolds.

Conclusions

- The incorporation of chitosan into scaffold resulted in decreasing compressive strength due to the weaker interfacial bonding between chitosan and HA matrix.
- Regardless of the bacteria type, increasing $AgNO_3$ and reducing HA resulted in more antibacterial activity.
- As $AgNO_3$ increased pores size was decreased with ease of their interconnection. Moreover, presence of $AgNO_3$ in scaffold affects pore size and their interconnection.
- Increasing $AgNO_3$ and reduction of Hydroxyapatite increased the adsorption and hence, swelling ratio.
- With increasing $AgNO_3$, stability and sustainability of delivery enhanced, such that after 1000 hours, only 42% of drug was released in C3 sample whereas in C2 sample 60% of vancomycin was released. less HA in scaffold resulted in higher drug release.

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Artificial Intelligence-Based Assessment of Industrial Transformation Pathways in Iran's Food Industry

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Abstract

The development of non-oil exports has become a strategic priority for Iran due to vulnerability associated with oil dependence and the need for sustainable economic growth. Within this framework, the food manufacturing sector, as a key component of the agricultural value chain, possesses considerable potential for value creation, employment generation, and integration into regional and global markets. However, despite significant production capacities and geographical advantages, Iran's food industry has not fully achieved its export potential, highlighting the need for effective industrial transformation pathways. This study develops an artificial intelligence-based framework to assess transformation pathways in Iran's food industry by integrating historical evidence with expert knowledge. Machine learning models, including Random Forest and XGBoost, were applied using annual time-series data from 2000 to 2022 to identify major determinants of food industry export performance. The predictive results were interpreted through Explainable Artificial Intelligence (SHAP) to reveal the contribution and direction of influential factors. Furthermore, an expert-based Self-Organizing Map (SOM) clustering approach was employed using perceptions of 150 industrial experts to identify feasible transformation priorities. The results indicate that variables associated with food manufacturing capacity, industrial productivity, and agricultural value creation provide the largest contributions to the predictive structure of food export performance, while the exchange rate represents an important but comparatively lower-ranked factor. The expert-based analysis, however, identifies exchange rate instability, policy uncertainty, and weak international market capabilities as major institutional and strategic constraints affecting the practical realization of export potential.

Keywords: Artificial Intelligence; Food Industry; Machine Learning.

چکیده

توسعه صادرات غیرنفتی برای عبور از آسیب‌پذیری اقتصاد وابسته به نفت و دستیابی به رشد پایدار، اولویتی راهبردی برای ایران است. در این میان، صنایع تبدیلی غذایی به‌عنوان پیونددهنده زنجیره ارزش کشاورزی با بازارهای منطقه‌ای، از مزیت جغرافیایی و توان اشتغال‌زایی بالایی برخوردار است؛ اما این بخش هنوز نتوانسته به پتانسیل واقعی صادراتی خود دست یابد. این مقاله با طراحی چارچوبی مبتنی بر هوش مصنوعی، داده‌های تاریخی (۲۰۰۰ تا ۲۰۲۲) را با ادراکات ۱۵۰ خبره صنعتی تلفیق کرده تا مسیرهای تحول این صنعت را تبیین کند. یافته‌های حاصل از مدل‌های یادگیری ماشین با تبیین‌پذیری مدل SHAP نشان می‌دهد که متغیرهای «ظرفیت فرآوری مواد غذایی»، «بهره‌وری صنعتی» و «خلق ارزش در بخش کشاورزی»، بیشترین سهم را در ارتقای عملکرد صادراتی دارند؛ درحالی‌که نرخ ارز نقشی مهم اما با رتبه اثربخشی پایین‌تر ایفا می‌کند. در نقطه مقابل، تحلیل خوشه‌بندی خبره‌محور گلوگاه‌های اصلی در عدم تحقق این پتانسیل شامل «ناپایداری نرخ ارز»، «نااطمینانی در سیاست‌گذاری‌های دولتی» و «ضعف در بازاریابی و قابلیت‌های ورود به بازارهای بین‌المللی» را ریشه‌دار در موانع نهادی و استراتژیک می‌داند. از منظر اقتصاد صنعتی، پیام کلیدی مقاله این است که جهش صادراتی پایدار، بدون رفع نااطمینانی‌های سیاستی، ارتقای بهره‌وری زنجیره تأمین و توانمندسازی تجاری بنگاه‌ها، صرفاً با تکیه بر ابزار تعدیل نرخ ارز حاصل نخواهد شد.

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1.Introduction

International trade has long been recognized as a key driver of economic development by generating foreign exchange, facilitating technology transfer, enhancing productivity, and expanding production capacity (Krugman et al., 2018). However, excessive reliance on a limited range of export commodities exposes economies to external shocks and constrains long-term industrial competitiveness (Hausmann et al., 2007). Similar to many resource-dependent economies, Iran has historically relied heavily on oil revenues, making export diversification a strategic national priority. Accordingly, Iran's Seventh National Development Plan targets an annual 23% growth in non-oil exports to strengthen economic resilience and reduce dependence on petroleum revenues (Islamic Republic of Iran, 2023).

Within this strategy, agriculture and agro-based industries play a pivotal role because of their strong linkages with domestic production, employment, food security, and export diversification (Anderson, 2016; Abnar et al., 2020). Nevertheless, sustainable competitiveness increasingly depends on moving beyond raw agricultural exports toward higher value-added products through processing, branding, quality improvement, and integration into global value chains (Kaplinsky & Morris, 2001; Gereffi et al., 2005). Food manufacturing industries are therefore critical, as they transform agricultural raw materials into value-added products, reduce post-harvest losses, stabilize seasonal supply, create employment, and improve access to international markets (Wilkinson & Rocha, 2013; FAO, 2022). Compared with many capital-intensive industries, food manufacturing requires relatively moderate investment while offering substantial opportunities for industrial upgrading and export diversification (Torkamani & Zoghipour, 2008).

The strategic importance of this sector is evident in Iran's recent trade performance. Agricultural exports reached approximately USD 8.46 billion, accounting for 13.5% of total non-oil exports valued at USD 62.59 billion (IRICA, 2021). Processed food products, including dairy products, tomato paste, confectionery, and other processed agricultural goods, constitute a significant share of these exports. At the same time, considerable untapped opportunities remain in neighboring markets. Countries such as Saudi Arabia, the United Arab Emirates, Oman, Kuwait, and Qatar annually import billions of dollars of dairy products, while global imports of tomato paste exceed USD 4.5 billion, compared with Iran's exports of only USD 126 million (ITC, 2023). These figures highlight the substantial gap between Iran's existing export performance and its regional and global market potential.

Despite these advantages, Iran's food industry has not fully realized its international competitiveness. Previous studies have identified exchange rate instability, production inefficiencies, technological limitations, weak branding, inadequate marketing, quality-related issues, logistics constraints, and limited participation in global value chains as the principal barriers to export development (Sedaghat, 2007; Torkamani & Zoghipour, 2008; Nejatianpour & Esmaeili, 2016; Mousavi Khaledi et al., 2020). Most existing research has relied on conventional econometric approaches, particularly gravity models and panel-data techniques, to explain export performance through variables such as exchange rates, market size, trade costs, and economic distance (Wardani et al., 2018; Szekelyhidi, 2018; Bekele & Mersha, 2019). Although these studies have significantly advanced the understanding of trade determinants, many empirical applications rely on relatively predefined functional specifications and a limited set of theoretically selected relationships. Econometric approaches are not inherently restricted to linear relationships and can accommodate nonlinearities, interaction effects, structural breaks, and regime-dependent dynamics through appropriate model specifications. However, when the objective is exploratory prediction in the presence of multiple potentially interacting economic, technological, institutional, and structural variables, machine-learning methods can provide a complementary data-driven approach for identifying complex predictive patterns without requiring all functional relationships and interactions to be specified ex ante.

Addressing these complexities requires moving beyond the traditional objective of identifying export determinants toward designing Industrial Transformation Pathways, defined as strategic trajectories through which industries evolve toward more competitive, technologically advanced, sustainable, and globally integrated production systems (Dosi, 1982; Freeman & Perez, 1988; Perez, 2010; OECD, 2021). Such pathways emphasize the dynamic interaction among technological capabilities, innovation, organizational development, market positioning, institutional quality, and resource efficiency rather than production expansion alone. For emerging economies such as Iran, where industrial development is simultaneously influenced by macroeconomic instability, investment constraints, technological gaps, energy intensity, trade restrictions, and changing global market requirements, capturing all potentially nonlinear and interacting relationships through a single predefined empirical specification can be challenging. Data-driven machine-learning approaches can therefore complement conventional econometric analysis by exploring complex predictive patterns and interactions among multiple variables.

Recent advances in artificial intelligence (AI) and machine learning (ML) offer valuable tools for analyzing multidimensional and complex systems. Modern and widely used machine-learning algorithms, such as Random Forest and Extreme Gradient Boosting (XGBoost), are particularly well suited to capturing nonlinear relationships and complex interactions among variables (Breiman, 2001; Chen & Guestrin, 2016). Unlike some conventional econometric specifications that rely on predefined functional forms, these algorithms can flexibly model complex patterns in the data, making them useful complementary approaches for predictive analysis in multidimensional economic and industrial systems.Moreover, the emergence of Explainable Artificial Intelligence (XAI), particularly the SHAP framework, enables researchers to interpret AI models by quantifying the contribution of individual variables to prediction outcomes (Lundberg & Lee, 2017; Lundberg et al., 2020). Consequently, AI can move beyond prediction toward strategic knowledge discovery by identifying key transformation drivers, prioritizing industrial capabilities, and supporting evidence-based policymaking (Wuest et al., 2016; Kusiak, 2018; Tao et al., 2019). Nevertheless, applications of explainable AI for identifying industrial transformation pathways in agro-based industries, particularly in developing countries, remain scarce.

Accordingly, this study addresses a broader strategic question than previous export studies: Which economic, technological, structural, and managerial capabilities should be prioritized to transform Iran's food manufacturing industry into a competitive, technology-oriented, and globally integrated sector? To answer this question, the study proposes an integrated AI-based framework combining longitudinal time-series data with expert knowledge collected from industry stakeholders. Machine learning models identify and rank the dynamic drivers of export competitiveness, while expert-based analysis validates these findings and translates them into practical industrial transformation pathways. Unlike previous studies that primarily diagnose export determinants using conventional econometric techniques, this research integrates explainable artificial intelligence with industrial expertise to develop an evidence-based roadmap for transforming Iran's food manufacturing sector into a competitive, value-added, and globally connected industry.

2. Literature Review

2.1. Export Competitiveness in Food Manufacturing

Export competitiveness has long been recognized as a fundamental determinant of industrial development and economic diversification. Previous studies have primarily explained agricultural and food exports using macroeconomic variables, including exchange rates, income, production capacity, market size, and trade costs. International studies employing gravity models (Bekele & Mersha, 2019; Braha et al., 2017; Ebaidalla & Awad, 2015; Mosikari & Eita, 2016; Natale et al., 2015; Szekelyhidi, 2018; Wardani et al., 2018) consistently demonstrate that market size, economic distance, and exchange rate movements significantly influence export performance. Similar evidence has been reported for Iran, where gravity-based analyses identified exchange rates, GDP, sanctions, and production capacity as important determinants of agricultural and food exports (Abnar et al., 2020; Akbari et al., 2017; Harati et al., 2015; Khadiv & Asgari, 2020; Koochakzadeh & Karbasi, 2015; Shafiei & Aghapour Sabbaghi, 2016; Souri, 2017; Zarif et al., 2011; Ziyaee Bigdeli et al., 2013). Although these studies substantially improved the understanding of export determinants, they predominantly focused on explaining historical trade patterns rather than identifying future industrial development trajectories.

2.2. Industrial Transformation and Strategic Development

In this study, an industrial transformation pathway refers to a structured strategic trajectory through which a food manufacturing industry develops its productive, technological, organizational, market, and institutional capabilities to achieve sustained improvements in competitiveness and international market integration. Thus, the term refers not to a single intervention, but to a coherent configuration of capabilities and strategic priorities that can guide the sector's transition toward higher-value and more competitive production.

Recent industrial policy literature emphasizes that long-term competitiveness depends not only on production growth but also on industrial transformation through technological upgrading, productivity improvement, innovation, institutional quality, and value-chain integration (Dosi, 1982; Freeman & Perez, 1988; OECD, 2021; Perez, 2010). Accordingly, transformation pathways describe dynamic sequences of structural changes that enable industries to achieve sustainable competitiveness under changing economic and technological conditions. In agro-food industries, these pathways involve strengthening productivity, increasing value addition, improving quality standards, expanding market capabilities, and enhancing technological readiness rather than relying solely on traditional comparative advantages.

2.3. Artificial Intelligence in Industrial Decision-Making

The rapid development of artificial intelligence has expanded the analytical tools available for industrial research by facilitating the exploration of complex nonlinear relationships and interactions among multiple variables. Although econometric methods can accommodate such complexities through appropriate nonlinear, interaction-based, structural-break, or regime-dependent specifications, machine-learning approaches provide a flexible complementary framework when the underlying functional relationships are not known in advance or when multiple interactions may be relevant. Machine learning algorithms, particularly Random Forest (Breiman, 2001) and Extreme Gradient Boosting (Chen & Guestrin, 2016), have demonstrated high predictive performance in economic forecasting, industrial performance evaluation, and supply-chain analysis (Kusiak, 2018; Wuest et al., 2016). More recently, Explainable Artificial Intelligence (XAI) has addressed the interpretability challenge of machine learning models. The SHAP framework enables decomposition of model predictions into variable-specific contributions, thereby supporting transparent policy interpretation and evidence-based decision-making (Lundberg & Lee, 2017; Lundberg et al., 2020). Consequently, AI has evolved from a prediction tool into a strategic instrument for industrial policy analysis.

2.4. AI Applications in Industrial Transformation Studies

The application of AI has increasingly extended beyond forecasting toward supporting industrial transformation and strategic planning. Recent studies have employed machine learning to identify technological transition patterns, evaluate industrial resilience, optimize production systems, and prioritize development strategies in manufacturing and supply chains (Baryannis et al., 2019; Ivanov & Dolgui, 2020; Kusiak, 2018; Tao et al., 2019; Wuest et al., 2016). However, these applications remain concentrated in advanced manufacturing economies. In the food industry, particularly within developing countries, AI has been used mainly for prediction, demand forecasting, quality assessment, and process optimization, while studies integrating explainable AI with expert knowledge to formulate industrial transformation pathways remain extremely limited.

2.5. Research Gap and Contribution

Overall, existing literature has provided valuable insights into the determinants of agricultural and food exports, the challenges of export development, and the potential of artificial intelligence for industrial analysis. Nevertheless, three major gaps remain. First, previous studies have largely emphasized explaining export performance rather than identifying strategic transformation pathways. Second, while econometric approaches can explicitly model nonlinearities and interactions through appropriate specifications, empirical applications in this literature have often focused on a relatively limited set of predefined relationships among macroeconomic and trade variables. Machine-learning methods can complement these approaches by exploring broader predictive patterns and potentially complex interactions among macroeconomic, industrial, technological, and institutional factors. Third, few studies integrate longitudinal economic evidence with expert knowledge through explainable artificial intelligence to support industrial policymaking. Addressing these gaps, the present study proposes an integrated AI-based framework combining machine learning, SHAP explainability, and expert-based Self-Organizing Maps (SOM) to identify the critical capabilities and policy priorities required for transforming Iran's food manufacturing industry into a competitive, technology-oriented, and globally integrated sector. Unlike previous research, this framework moves beyond identifying what determines exports toward explaining how industrial transformation can be strategically achieved, thereby providing an evidence-based foundation for industrial policy and long-term sectoral development.

3. Materials and Methods

3.1. Research Design and Analytical Framework

This study develops an integrated artificial intelligence-based framework to assess industrial transformation pathways in Iran's food manufacturing sector. Unlike conventional studies that mainly focus on identifying determinants of export performance through econometric approaches, this research aims to move beyond factor identification and provide a strategic understanding of how industrial capabilities can be transformed toward a more competitive and globally integrated food manufacturing system.

The methodological framework consists of two complementary analytical stages. In the first stage, artificial intelligence-based time-series models are applied to identify the dynamic drivers of food industry export performance in Iran. This stage captures historical relationships between export performance and a set of macroeconomic, industrial, technological, and institutional factors over the period 2000–2022. Since industrial competitiveness is characterized by complex interactions, nonlinear relationships, and possible threshold effects, machine learning algorithms are employed instead of relying solely on traditional linear specifications.

In the second stage, an expert-based artificial intelligence clustering framework is developed to identify feasible transformation pathways. Although historical data provide evidence regarding the factors associated with export performance, they cannot fully capture managerial knowledge, institutional constraints, and practical implementation challenges. Therefore, expert knowledge from industrial managers, policymakers, exporters, and sectoral organizations is incorporated through an AI-based clustering approach.

The combination of these two analytical perspectives allows the study to answer two complementary questions:

1. Which factors have historically influenced the export competitiveness of Iran's food industry?
2. Which transformation pathways should be prioritized to enhance future industrial competitiveness?

Accordingly, the proposed framework combines historical evidence from machine learning models with forward-looking strategic insights derived from industrial stakeholders.

3.2. Data Sources and Variable Selection

The quantitative component of this study is based on annual time-series data covering the period 2000–2022, a timeframe selected to ensure the availability, consistency, and comparability of macroeconomic, industrial, and trade statistics. Data were compiled from several authoritative national and international sources, including the Central Bank of Iran (CBI), Statistical Center of Iran (SCI), Ministry of Industry, Mine and Trade (MIMT), Islamic Republic of Iran Customs Administration (IRICA), the World Bank, and the International Trade Centre (ITC). Following international trade theory and the industrial competitiveness literature, the annual export value of Iran's food manufacturing industry was selected as the dependent variable because export performance provides a comprehensive measure of industrial competitiveness, reflecting not only production capacity but also technological capability, product quality, international market access, and participation in global value chains. For developing economies, food manufacturing exports are particularly important because they generate substantially higher value added than exports of raw agricultural commodities, reduce post-harvest losses, create employment opportunities, and strengthen foreign exchange earnings (Torkamani & Zoghipour, 2008). Consistent with previous studies, export performance is therefore considered an appropriate proxy for assessing the competitive position and structural development of Iran's food manufacturing sector (Wardani et al., 2018; Abnar et al., 2020).

The explanatory variables were selected to capture the macroeconomic, industrial, technological, financial, and institutional dimensions influencing export competitiveness. Macroeconomic conditions were represented by the inflation rate, exchange rate, gross domestic product (GDP), gross fixed capital formation, interest rate and. Inflation reflects macroeconomic instability and rising production costs, whereas the exchange rate affects international price competitiveness while excessive volatility may discourage investment and increase production uncertainty (Abnar et al., 2020; Kohansal & Mahmoudi, 2020; Mousavi Khaledi et al., 2020). The exchange-rate variable is measured in nominal terms. A nominal exchange rate was retained to capture the observed domestic-currency price of foreign currency and its associated macroeconomic and cost effects during the study period. Because inflation is included separately as an explanatory variable, the model allows the predictive contribution of exchange-rate movements to be evaluated alongside domestic price instability rather than treating nominal depreciation as a direct measure of changes in relative international prices. Accordingly, the exchange-rate variable should not be interpreted as a direct measure of real price competitiveness. The exchange-rate variable is measured as the nominal exchange rate of the Iranian rial against the US dollar (IRR/USD), expressed as Iranian rials per US dollar. GDP and gross fixed capital formation represent the overall scale of economic activity, production infrastructure, and investment capacity that support industrial upgrading and export expansion, while the interest rate captures financing costs and firms' ability to invest in technology and production (Anderson, 2016; Tinbergen, 1962). Industrial and technological capabilities were represented by food machinery imports, agricultural value added, food manufacturing output, and food industry productivity. Imports of food-processing machinery serve as a proxy for technology acquisition and industrial modernization, agricultural value added reflects the availability and quality of domestic raw materials, food manufacturing output measures industrial production capacity, and productivity represents the efficiency with which resources are transformed into internationally competitive products, which Porter (1990) identifies as the fundamental source of sustainable competitiveness. Finally, an economic sanctions dummy variable was incorporated to capture major structural shocks affecting Iran's industrial and trade environment. The variable was coded as 0 for 2000–2009, 1 for 2010–2015, 0 for 2016–2018, and 1 for 2019–2022, representing periods of intensified international sanctions that substantially affected financial transactions, technology transfer, industrial investment, and international trade. Similar structural shock variables have been widely employed in empirical studies examining the impact of sanctions on Iran's trade performance and export competitiveness (Ziyaee Bigdeli et al., 2013). Collectively, these variables provide a comprehensive representation of the economic, industrial, technological, and institutional factors shaping the export performance of Iran's food manufacturing industry.

3.3. Artificial Intelligence-Based Time-Series Modeling

To identify nonlinear relationships between food industry exports and explanatory variables, two machine learning algorithms are applied: Random Forest (RF) and Extreme Gradient Boosting (XGBoost).

Machine-learning approaches are increasingly used in economic and industrial studies because they provide flexible tools for capturing complex predictive patterns and interactions among variables without requiring the researcher to specify all functional forms and interaction structures in advance.

3.3.1. Random Forest Model

The first machine learning algorithm employed in this study is the Random Forest (RF) model, introduced by Breiman (2001). Random Forest belongs to the family of ensemble learning methods and constructs a large number of independent decision trees using randomly selected subsets of observations and explanatory variables. The final prediction is obtained by aggregating the results of individual trees, which improves predictive stability and reduces the risk of overfitting.

The application of Random Forest is particularly relevant for industrial competitiveness analysis because the determinants of export performance are rarely independent or linearly related. For instance, the effect of technological upgrading on food industry exports may depend on investment capacity, exchange rate conditions, availability of agricultural inputs, and macroeconomic stability. Econometric regression models can represent nonlinearities and interaction effects when these relationships are specified appropriately. However, such specifications generally require the researcher to define the relevant functional forms and interactions ex ante. Random Forest provides a complementary data-driven approach that can flexibly explore complex nonlinear patterns and interactions directly from the observed data.

Another important advantage of Random Forest is its ability to estimate the relative importance of explanatory variables. In this research, the model is not used merely as a forecasting tool; rather, it serves as an exploratory mechanism to identify which economic and industrial factors have the strongest association with export competitiveness. This characteristic is particularly valuable in the context of industrial transformation studies, where the objective is not only prediction but also identifying strategic intervention areas.

Following Breiman (2001), the Random Forest model can be represented as an ensemble of multiple decision trees:

$$\hat{Y} = \frac{1}{B}\sum_{b=1}^{B} T_b\,(X) \tag{1}$$

where $T_b(X)$ represents the prediction generated by the b-th decision tree and B represents the total number of trees. Increasing the number of trees generally improves prediction robustness while maintaining model stability.

3.3.2. Extreme Gradient Boosting (XGBoost) Model

The second artificial intelligence approach applied in this study is Extreme Gradient Boosting (XGBoost), developed by Chen and Guestrin (2016). XGBoost is an advanced implementation of gradient boosting algorithms designed to improve predictive performance through sequential learning. Unlike Random Forest, where trees are independently constructed and subsequently combined, XGBoost develops trees sequentially, with each new tree attempting to correct the prediction errors of previous models.

The methodological advantage of XGBoost is its capability to capture complex nonlinear relationships while incorporating regularization mechanisms that reduce model complexity and prevent overfitting. These characteristics have resulted in widespread application of XGBoost in economic forecasting, financial modelling, industrial analytics, and decision-support systems.

In the context of Iran's food industry, export competitiveness is influenced by simultaneous interactions among production capacity, technology acquisition, macroeconomic conditions, and external constraints. XGBoost is therefore appropriate because it can identify hidden relationships that may not be observable through conventional analytical approaches.

The general objective function of XGBoost can be expressed as:

$$Obj = \sum_i l(y_i, \hat{y}_i) + \sum_k \Omega(f_k) \tag{2}$$

where the first component represents the prediction error and the second component controls model complexity through regularization (Chen & Guestrin, 2016).

The combination of Random Forest and XGBoost provides methodological robustness because both models are based on tree-learning structures but approach nonlinear modelling from different perspectives. If both algorithms identify similar influential factors, confidence in the identified transformation drivers increases.

3.3.3. Model Training, Validation, and Accuracy Evaluation

Since the objective of this study is to analyze industrial dynamics over time, special attention is given to preserving the temporal structure of the dataset. Unlike conventional machine learning applications where random sampling is commonly applied, random splitting of time-series observations may generate information leakage because future information can unintentionally influence model training. Therefore, an expanding-window time-series cross-validation procedure was employed to preserve the temporal structure of the dataset. The model was initially trained on observations from 2000–2015 and used to predict 2016; the training window was then expanded by one year and the procedure repeated sequentially through 2022. Model performance was evaluated across the resulting out-of-sample predictions using MAPE rather than relying on a single train–test split. The performance of competing AI models is assessed using the Mean Absolute Percentage Error (MAPE). MAPE is selected because it provides an intuitive measure of prediction accuracy by expressing prediction errors as percentages, allowing direct comparison between models.The MAPE is calculated as:

$$MAPE = \frac{100}{n} \sum_{i=1}^{n} | \frac{y_i - \hat{y}_i}{y_i} | \tag{3}$$

where represents the observed export value and represents the predicted value. The model with the lowest MAPE value is considered the most accurate predictive framework and is subsequently selected for explainability analysis. where (yi) represents the observed export value and (^yi) represents the predicted value.

The model with the lowest MAPE value is considered the most accurate predictive framework and is subsequently selected for explainability analysis.

3.4. Explainable Artificial Intelligence Analysis

Although machine learning models provide strong predictive capabilities, their complex structures often create interpretation challenges, commonly referred to as the "black-box" problem. In policy-oriented research, predictive accuracy alone is insufficient because decision-makers need to understand why a model produces a particular outcome and which factors should be targeted through interventions. Therefore, this study incorporates Explainable Artificial Intelligence (XAI) using the SHAP (SHapley Additive exPlanations) framework proposed by Lundberg and Lee (2017).

In this research, SHAP analysis serves three main interpretive purposes. First, it identifies the variables that provide the largest contributions to the model's predictions of Iran's food industry export performance. For example, the analysis can indicate whether variables related to technological upgrading, productivity, exchange-rate conditions, or investment capacity contain relatively greater predictive information within the fitted model.

Second, SHAP values help interpret the direction and pattern of variable contributions to individual model predictions. A variable may have high predictive importance without exhibiting a uniformly positive or negative contribution across all observations. For example, machinery imports may be associated with higher predicted export performance under some observed conditions while contributing less strongly under others, reflecting possible interactions and nonlinearities captured by the model.

Third, SHAP analysis provides an interpretable basis for connecting predictive patterns identified by the machine-learning model with industrial policy discussion. These results should not be interpreted as establishing causal effects or identifying policy interventions with guaranteed impacts. Rather, they highlight patterns and variables that warrant further economic interpretation and policy attention.

Thus, XAI represents a critical methodological component of this study because it makes the predictive structure of the artificial intelligence model more transparent and facilitates the interpretation of model-based evidence within a broader industrial policy framework.

3.5. Expert-Based AI Clustering Framework for Transformation Pathway Identification

Historical data analysis provides valuable evidence regarding the factors associated with export competitiveness; however, industrial transformation is a forward-looking process involving strategic choices, organizational capabilities, and institutional constraints that cannot be fully captured through quantitative indicators alone.

Therefore, this study incorporates expert knowledge through an AI-based clustering framework. The purpose of this stage is not to replace empirical modelling but to complement it by integrating the tacit knowledge of industrial stakeholders into the pathway identification process.

A structured questionnaire was developed based on two sources: (1) variables and predictive patterns identified as influential within the AI time-series models and SHAP analysis, and (2) the broader literature on industrial transformation, Industry 4.0 adoption, competitiveness, and global value chain integration. The questionnaire evaluated the perceived importance and readiness of different transformation dimensions, including:

1. technological upgrading and Industry adoption;
2. production efficiency and productivity improvement;
3. export capability development;
4. international standards and quality management;
5. supply chain resilience;
6. innovation capacity;
7. branding and international marketing;
8. institutional and financial barriers.

The survey was conducted among 150 experts and industrial stakeholders selected from different components of Iran's food manufacturing ecosystem. Participants included food industry managers, exporters, representatives of industrial associations, experts introduced through the Iran Chamber of Commerce, governmental organizations related to industry and agriculture, and relevant professional organizations. The objective of collecting expert opinions was not to obtain simple rankings of factors but to identify underlying strategic patterns among stakeholders with different perspectives and experiences.

3.5.1. Self-Organizing Map (SOM) Approach

To analyze expert responses, this study applies the Self-Organizing Map (SOM) algorithm developed by Kohonen (1990). SOM is an unsupervised artificial neural network technique designed to identify hidden structures and patterns within multidimensional datasets. Unlike supervised machine learning methods that require predefined classes, SOM discovers natural groupings based on similarities among observations. This characteristic makes it suitable for transformation pathway analysis, where the objective is to uncover alternative strategic configurations rather than classify observations according to predetermined categories.

In this study, each expert represents an observation characterized by their evaluation of transformation dimensions. The SOM algorithm maps experts with similar strategic perceptions into the same cluster, allowing the identification of distinct perspectives regarding the future direction of Iran's food industry. The resulting clusters are interpreted as alternative transformation pathways. For example, one cluster may emphasize technology-intensive transformation through automation and digitalization, while another may prioritize export market expansion, branding, and global value chain integration. A third cluster may reflect a resilience-oriented pathway emphasizing domestic capability development and supply chain security. The advantage of SOM is that it enables the identification of complex strategic patterns that may remain hidden when using traditional statistical ranking methods.

3.6. Integration of AI Outputs for Developing Industrial Transformation Pathways

The final analytical stage integrates the outputs of machine learning models, explainable artificial intelligence analysis, and expert-based clustering to develop an evidence-based framework for identifying industrial transformation pathways in Iran's food manufacturing sector. The time-series machine learning models provide empirical insights into the historical dynamics of export competitiveness by capturing the complex and nonlinear relationships between industrial, technological, macroeconomic, and external factors. Subsequently, the SHAP-based explainability analysis reveals the relative contribution and direction of influence of each determinant, transforming the predictive outcomes of artificial intelligence models into interpretable strategic insights. In parallel, the expert-based SOM clustering approach incorporates the tacit knowledge and practical perspectives of industrial stakeholders to identify feasible transformation trajectories under existing institutional and market conditions. Accordingly, the three stages serve complementary rather than independent validation roles: ML identifies predictive patterns, SHAP interprets their contribution, and expert-based SOM translates these empirical insights into distinct strategic configurations. The resulting configurations are interpreted as transformation pathways based on their dominant combinations of capabilities and priorities.

By integrating these three analytical layers, this study establishes a comprehensive transformation pathway framework that combines historical evidence, model-based interpretation, and industry-specific strategic knowledge. This integrated approach addresses an important limitation in previous export competitiveness studies, which have predominantly concentrated on identifying statistical determinants of trade performance while providing limited guidance on how industries can strategically transform toward higher levels of competitiveness. Therefore, the proposed framework extends beyond explaining export performance and provides a systematic approach for identifying the technological capabilities, industrial priorities, and policy interventions required to transform Iran's food industry into a more competitive, technology-oriented, and globally integrated manufacturing sector.

Given the limited sample size, model stability was assessed through repeated resampling and sensitivity analysis. The feature-importance rankings remained broadly consistent across validation runs, indicating that the main findings were not driven by a small number of individual observations.

4. Results

4.1. Machine Learning Model Performance and Key Predictive Factors of Export Performance

The first analytical stage aimed to identify the main variables contributing to the predictive representation of export performance in Iran's food manufacturing industry using machine-learning-based approaches. The objective of this stage is to examine patterns of association and predictive contribution within the observed data rather than to establish causal relationships among the explanatory variables and export performance.

Two ensemble learning algorithms, namely Random Forest (RF) and Extreme Gradient Boosting (XGBoost), were employed to model the relationship between food industry exports and explanatory variables during 2000–2022. The models were evaluated using the Mean Absolute Percentage Error (MAPE) criterion. The results indicate that both models were able to capture the general pattern of export dynamics; however, XGBoost achieved superior predictive performance compared with Random Forest.

Table 1. Performance comparison of machine learning models

Model	Training MAPE	Testing MAPE	Performance ranking
Random Forest	8.9%	13.4%	Second
XGBoost	6.3%	10.1%	First

Source: Research Finding

The lower prediction error obtained by XGBoost confirms its stronger capability in representing the complex nonlinear structure of food export dynamics. Therefore, XGBoost was selected as the final predictive model for the subsequent explainable artificial intelligence analysis.

The relatively low prediction error of the selected model suggests that export competitiveness in Iran's food manufacturing sector is not adequately represented by a single explanatory factor. Instead, the model captures export performance through the combined contribution of variables related to industrial capabilities, value creation, productivity conditions, market competitiveness, and macroeconomic conditions.

This finding is particularly important in the context of Iran, where export performance is often interpreted mainly through exchange rate movements or external constraints. The machine learning results suggest that, although macroeconomic variables contribute to the prediction of export outcomes, variables associated with internal industrial capabilities provide a larger share of the predictive information captured by the model.

The gain-based feature importance analysis of the XGBoost model indicates that variables related to production capacity, industrial value creation, and productivity provide the largest contributions to the predictive structure of the model.

Table 2. Relative importance of explanatory variables based on XGBoost gain

Rank	Variable	Relative importance (%)	Economic interpretation
1	Food manufacturing output value	24.1	Represents industrial scale and production capacity
2	Food industry productivity	19.8	Determines production efficiency and cost competitiveness
3	Agricultural value added	15.6	Reflects the strength of upstream supply chains
4	Exchange rate	11.7	Captures changes in relative prices and export competitiveness
5	Gross fixed capital formation	9.8	Indicates long-term expansion of productive capacity
6	Machinery imports	7.8	Supports technological upgrading and process improvement
7	Inflation rate	5.9	Represents macroeconomic instability and cost uncertainty
8	Interest rate	3.4	Affects access to financial resources and investment conditions
9	Sanctions intensity	1.9	Represents external constraints with relatively lower direct predictive contribution

Source: Research Finding

The prominence of food manufacturing output value indicates that this variable provides the largest gain contribution to the predictive structure of the XGBoost model. This result highlights the importance of industrial scale and production capacity in explaining variation in food export performance. In substantive terms, industries that successfully participate in international markets require not only access to agricultural resources but also the capacity to transform these resources into standardized, high-quality, and internationally competitive products.

Food industry productivity represents the second-largest source of gain in the model. Its high importance indicates that differences in production efficiency provide substantial predictive information regarding export performance within the fitted model. This pattern is consistent with the economic mechanisms through which higher productivity may support export competitiveness, including lower unit costs, improved resource utilization, reduced production losses, and a greater capacity to meet quality and market requirements. However, the machine-learning results do not independently establish these mechanisms as causal effects.

Similarly, the high gain contribution of agricultural value added emphasizes the importance of the relationship between agricultural production and downstream food manufacturing. A competitive food industry depends not only on processing capacity but also on the availability, quality, and economic performance of upstream agricultural supply chains. Export development should therefore be considered within an integrated agricultural–industrial value chain rather than as an isolated manufacturing activity.

Machinery imports provide a moderate contribution to the predictive structure of the model. This result suggests that technological upgrading and modern production equipment contain relevant information for explaining export performance, although their contribution is smaller than that of production capacity and productivity-related variables. Technology acquisition alone is therefore unlikely to represent a sufficient condition for export competitiveness; its effectiveness depends on complementary factors such as productivity management, organizational capabilities, market access, and the effective utilization of installed production capacity.

The exchange rate also makes a substantial gain contribution to the model. However, the gain measure does not indicate whether the effect of exchange rate movements on exports is positive, negative, or nonlinear. These patterns are examined separately in the subsequent SHAP analysis. The importance of the exchange rate nevertheless indicates that changes in relative prices and broader macroeconomic conditions provide relevant predictive information for the model.

Sanctions intensity has the lowest predictive contribution among the variables included in the fitted model. Conditional on the other variables considered, this result indicates that the sanctions variable provides less incremental predictive information for the model's export predictions than the principal production-, productivity-, and value-creation-related variables.

This finding should not be interpreted as evidence that sanctions have a limited economic or causal effect on Iran's food industry. Sanctions may influence export performance indirectly through multiple channels, including financial transactions, access to imported technology and intermediate inputs, exchange-rate instability, investment conditions, transportation costs, and broader macroeconomic uncertainty. Some of these channels may also be represented by other variables included in the model. Consequently, the relatively low predictive contribution of the sanctions variable should be interpreted only as a characteristic of the fitted predictive model and the selected set of variables, rather than as a measure of the overall economic impact of sanctions.

4.2. Explainable AI Analysis Using SHAP: Understanding the Direction and Economic Meaning of Export Drivers

Although machine learning models can provide strong predictive performance, the internal structure through which explanatory variables contribute to individual predictions is often difficult to interpret. In the context of industrial policy and transformation strategy, identifying variables with high predictive importance alone is insufficient; policymakers also need to understand how individual variables contribute to model predictions and whether these contributions are predominantly positive, negative, or nonlinear. Therefore, the present study applies the SHAP (Shapley Additive Explanations) approach to interpret the output of the selected XGBoost model.

The SHAP analysis complements, rather than replicates, the gain-based feature importance analysis presented in Table 2. XGBoost gain measures the contribution of a variable to improvements in the model's tree-based objective function during the construction of decision trees. SHAP analysis, in contrast, decomposes individual model predictions into variable-specific marginal contributions. The two approaches therefore provide different measures of model importance and should not be interpreted as interchangeable.

For each explanatory variable, the mean absolute SHAP value measures the average magnitude of its contribution to model predictions across all observations. For comparability across variables, these values were normalized by dividing each variable's mean absolute SHAP value by the sum of the mean absolute SHAP values across all explanatory variables. The resulting normalized values are reported in Table 3 as relative SHAP importance. Accordingly, the values in Table 3 sum to one by construction and should not be interpreted as raw mean absolute SHAP values.

Because the absolute magnitude of SHAP values does not indicate whether a variable increases or decreases the predicted outcome, the direction and pattern of each relationship were examined separately using signed SHAP values. The classification of effects reported in Table 3 is therefore based on the signed SHAP results and their distribution across observations rather than on the normalized absolute SHAP importance values.

The SHAP analysis broadly supports the main pattern identified by the gain-based feature importance analysis while providing a distinct interpretation of the fitted model. Variables associated with industrial capacity, productivity, and value creation account for the largest average contributions to model predictions, whereas the signed SHAP analysis provides additional evidence regarding the direction and potential nonlinear pattern of these contributions.

Table 3. Ranking and interpretation of export competitiveness drivers based on SHAP values

Rank	Variable	Normalized mean absolute SHAP importance	Direction from signed SHAP analysis	Strategic interpretation
1	Food manufacturing output value	0.228	Positive	Expansion of industrial capacity and production scale
2	Food industry productivity	0.206	Positive	Reduction of production costs and improvement of competitiveness
3	Agricultural value added	0.147	Positive	Strengthening raw material supply and value chains
4	Exchange rate	0.129	Nonlinear	Short-term competitiveness gains but uncertainty effects
5	Gross fixed capital formation	0.102	Positive	Long-term industrial capacity development
6	Machinery imports	0.074	Positive but conditional	Technology improvement depending on absorption capacity
7	Inflation rate	0.061	Negative	Higher uncertainty and production costs
8	Interest rate	0.036	Negative	Higher financing constraints
9	Sanctions intensity	0.017	Limited negative effect	External constraint with lower direct impact

Source: Research Finding, Note: Normalized SHAP importance is calculated by dividing each variable's mean absolute SHAP value by the sum of mean absolute SHAP values across all explanatory variables. Therefore, the reported values sum to 1 by construction. The direction of effects is assessed separately using signed SHAP values.

The prominence of food manufacturing output value in the SHAP ranking indicates that this variable makes the largest average contribution to the model's predictions of export performance. From an economic perspective, this pattern is consistent with the argument that export competitiveness is closely associated with the productive scale and capacity of the domestic food industry.

A higher production scale allows firms to benefit from economies of scale, reduce unit costs, maintain stable supply for foreign customers, and comply with international market requirements. Therefore, increasing the capacity and efficiency of food processing industries represents a central pathway for improving Iran's position in regional and global food markets.

The second most influential factor is productivity. The strong contribution of productivity confirms that the competitiveness challenge of Iran's food industry is not merely a production volume issue but largely a productivity issue. In international markets, particularly in neighboring countries with increasing competition from Turkey, Saudi Arabia, and other regional producers, firms need to compete through efficiency, quality consistency, and supply reliability rather than relying only on lower prices.

The SHAP results also highlight the important role of agricultural value added. This finding supports the argument that food manufacturing transformation should be approached through an integrated agriculture–industry value chain perspective. Iran possesses considerable agricultural potential; however, the economic benefits of this potential depend on the ability to transform agricultural outputs into processed products with higher value added.

Table 4. Economic interpretation of major SHAP-based findings

Variable	SHAP interpretation	Implication for industrial transformation
Food manufacturing output value	Higher industrial output increases export potential	Promote scalable and export-oriented production
Productivity	Efficiency improvements strongly enhance competitiveness	Focus on process optimization and waste reduction
Agricultural value added	Strong agricultural-industrial linkage supports exports	Develop integrated value chains
Exchange rate	Effect depends on production conditions	Avoid excessive reliance on currency depreciation
Machinery imports	Benefits depend on managerial and technical capability	Improve technology absorption capacity
Inflation	Creates uncertainty and reduces competitiveness	Strengthen macroeconomic stability
Interest rate	Limits investment capacity	Improve industrial financing mechanisms
Sanctions	Lower direct contribution than internal factors	Focus on domestic capability building

Source: Research Finding

Exchange Rate Effects: Beyond the Traditional Export Incentive Mechanism

One of the most important findings of the SHAP analysis concerns the role of the exchange rate. Conventional trade theory suggests that currency depreciation can improve export price competitiveness when it lowers the relative price of domestic goods compared with foreign goods. However, because the exchange-rate variable in this study is measured in nominal terms, its SHAP contribution should not be interpreted as a direct measure of changes in real international price competitiveness. In Iran, where substantial domestic inflation occurred during 2000–2022, nominal depreciation may partly reflect differences in domestic and foreign price levels. The exchange-rate SHAP values therefore capture the predictive contribution of nominal exchange-rate movements conditional on the other variables included in the model, including inflation, rather than a pure real-exchange-rate effect.

The positive effect of exchange rate depreciation appears only when firms are able to maintain stable production costs and access necessary inputs. In contrast, excessive exchange rate volatility increases uncertainty, disrupts production planning, changes input prices, and reduces the ability of exporters to commit to long-term international contracts.

Therefore, the challenge for Iran's food industry is not necessarily the absolute level of the exchange rate, but rather the unpredictability and volatility of exchange rate changes. This distinction is particularly important because export-oriented industries require long-term planning, stable contracts, and predictable cost structures.

The Role of Technology and Machinery: A Supporting Rather Than Dominant Factor

The SHAP results place machinery imports below production capacity and productivity variables. This finding provides an important policy implication. Although technological modernization is necessary for industrial transformation, technology acquisition alone cannot generate competitiveness. The effectiveness of imported machinery depends on complementary capabilities, including:

1. managerial skills;
2. maintenance capabilities;
3. workforce expertise;
4. quality management systems;
5. market-oriented production strategies.

Therefore, technological transformation in Iran's food industry should not be interpreted merely as purchasing advanced equipment, but rather as developing the organizational capabilities required to effectively utilize technology.

Limited Direct Impact of Sanctions on Food Export Competitiveness

An important and potentially counterintuitive finding of this research is the relatively low SHAP contribution of sanctions intensity compared with domestic industrial variables.

This does not imply that sanctions have had no consequences. Sanctions have affected financial channels, investment flows, technology access, and international business relationships. However, the model suggests that within the food manufacturing sector, structural domestic factors have played a more decisive role in determining export competitiveness.

Several explanations can be considered. First, food products generally experience stable regional demand and are less dependent on highly specialized global supply chains compared with technology-intensive industries. Second, Iran's geographical proximity to neighboring markets provides relatively accessible export opportunities. Third, many barriers to export expansion originate from internal constraints, including production efficiency, market development, branding, and regulatory uncertainty.

Therefore, improving food export performance requires addressing internal transformation capabilities rather than relying solely on external explanations.

4.2.1. Strategic Implications Derived from Explainable AI

The SHAP analysis provides evidence that the transformation of Iran's food industry should follow a capability-oriented strategy. The results suggest that policy interventions should prioritize:

1. Increasing industrial productivity rather than only expanding production volume;
2. Strengthening agricultural–industrial value chains to increase domestic value creation;
3. Reducing economic uncertainty caused by excessive price and exchange rate fluctuations;
4. Improving technology absorption capacity instead of focusing only on machinery acquisition;

Developing export capabilities, including branding, marketing, and international market integration.

Overall, the explainable AI results demonstrate that the future competitiveness of Iran's food industry depends primarily on strengthening internal industrial capabilities. The findings provide the empirical foundation for the next analytical stage, where expert knowledge is incorporated to identify feasible transformation pathways and prioritize strategic interventions.

4.3. Expert-Based Artificial Intelligence Clustering and Identification of Industrial Transformation Pathways

While the machine learning and explainable AI analyses provide evidence regarding the historical drivers of export competitiveness, industrial transformation cannot be designed solely based on quantitative relationships. The transition of an industry toward a more competitive and globally integrated structure requires consideration of institutional conditions, managerial capabilities, market constraints, and practical experiences of industrial stakeholders.

Therefore, the third analytical stage incorporated expert knowledge through an Expert-Based Artificial Intelligence Clustering Framework. The purpose of this stage was not to replace empirical findings obtained from historical data, but rather to complement them by identifying feasible transformation directions from the perspective of industrial actors.

A total of 150 experts, including managers of food manufacturing firms, exporters, representatives of industry associations, specialists from the Iran Chamber of Commerce, government organizations, and relevant professional bodies, participated in the survey. The questionnaire was designed based on two sources: (1) the determinants identified by the XGBoost-SHAP analysis and (2) the challenges and transformation factors reported in previous industrial competitiveness studies. Thus, the ML-SHAP results served as an empirical input to the expert survey by identifying the economic, industrial, and technological factors with greater predictive relevance. Expert assessment was then used to examine how these factors, together with broader industry-specific capabilities, could be organized into feasible strategic configurations.

Respondents evaluated the importance and feasibility of different transformation capabilities, including production competitiveness, productivity improvement, technology adoption, market development, branding, export strategy, supply chain integration, regulatory environment, and macroeconomic stability.

After data standardization, the Self-Organizing Map (SOM) algorithm was applied to identify groups of experts with similar perceptions regarding industrial transformation priorities. Unlike conventional clustering methods, SOM is a neural network-based unsupervised learning technique capable of reducing multidimensional expert opinions into meaningful strategic clusters while preserving the relationships among observations (Kohonen, 2001). The final number of four clusters was determined based on the SOM clustering structure and the interpretability of the resulting expert groups. The four clusters represented distinct and internally coherent combinations of transformation priorities, including market development, productivity improvement, institutional stability, and technological upgrading. These clusters were therefore interpreted as transformation pathways because each represents a distinct strategic configuration of capabilities and priorities identified from expert assessments, rather than a predetermined classification.

The results identified four major strategic clusters representing different transformation pathways for Iran's food industry.

Table 5. Expert-based SOM clustering results for industrial transformation pathways

Cluster	Main strategic orientation	Share of experts (%)	Main characteristics
Cluster 1	Market-oriented transformation and internationalization	34.7	Emphasis on branding, international marketing, market access, export networks
Cluster 2	Productivity and industrial efficiency improvement	28.0	Focus on cost reduction, operational efficiency, quality improvement
Cluster 3	Institutional and policy transformation	21.3	Emphasis on regulatory stability, predictable policies, stakeholder participation
Cluster 4	Technology and innovation upgrading	16.0	Focus on digitalization, automation, Industry 4.0 capabilities

Source: Research Finding

4.3.1. Market Development and Branding as the Dominant Transformation Pathway

The largest expert cluster was associated with market-oriented transformation, accounting for approximately 35% of respondents. Experts identified weak international marketing capabilities, insufficient branding, limited presence in foreign distribution networks, and inadequate knowledge of target markets as among the most important barriers limiting Iran's food export expansion.

This finding provides an important complement to the machine learning results. Although the XGBoost model identified production capacity and productivity as the main historical drivers of exports, expert analysis reveals that converting production capability into sustainable export growth requires market-facing capabilities.

Iran possesses significant advantages in the food sector, including agricultural diversity, geographical proximity to major consumer markets, competitive production costs, and cultural compatibility with regional food preferences. However, these advantages have not been fully transformed into international market share due to limited branding strategies and weak international commercial networks.

Experts particularly emphasized that many Iranian food products compete mainly through price advantages rather than through recognized brands, differentiated products, and consumer loyalty. Therefore, future transformation strategies should move from a commodity-export approach toward a brand-based export model.

Table 6. Priority barriers identified by experts in market-oriented transformation

Barrier	Importance score (0–100)
Weak international branding	87.4
Limited foreign market development activities	84.9
Lack of international distribution networks	81.6
Insufficient export marketing capabilities	79.8
Limited product differentiation	76.5

Source: Research Finding

4.3.2. Productivity Enhancement and Industrial Efficiency Pathway

The second major cluster focused on improving productivity and operational efficiency. Approximately 28% of experts considered productivity improvement as the most critical pathway for strengthening competitiveness.

This result is highly consistent with the SHAP analysis, where food industry productivity emerged as one of the most influential determinants of export performance.

Experts emphasized that many food manufacturing firms face challenges related to:

1. inefficient production processes;
2. high material waste;
3. energy consumption intensity;
4. limited process optimization;
5. insufficient quality management systems.

The findings indicate that competitiveness cannot be achieved only through increasing production capacity. Instead, firms must improve their ability to produce internationally acceptable products at competitive costs.

This pathway suggests that industrial transformation policies should encourage process innovation, lean manufacturing practices, quality certification systems, and productivity-oriented investment.

Table 7. Productivity-related transformation priorities identified by experts

Priority area	Importance score (0–100)
Reduction of production costs	86.2
Improvement of production efficiency	84.7
Reduction of waste and losses	82.3
Quality management improvement	80.9
Supply chain optimization	78.6

Source: Research Finding

4.3.3. Institutional Stability and Policy Transformation Pathway

The third cluster emphasized the role of institutional and policy conditions. Approximately 21% of experts considered regulatory uncertainty and unstable economic policies among the most significant constraints affecting export competitiveness.

A recurring issue identified by experts was that Iranian food manufacturers face difficulties not necessarily because of the absolute level of production costs, but because of unpredictability in economic conditions.

In particular, experts highlighted:

1. exchange rate volatility;
2. sudden changes in export regulations;
3. inconsistent trade policies;
4. limited participation of industrial stakeholders in policy formulation.

The findings indicate that export competitiveness requires a stable business environment where firms can plan production, investment, and international contracts over longer periods. Experts also emphasized the importance of balancing domestic market considerations with export development objectives. In some cases, policies designed to protect domestic consumers may unintentionally restrict industrial export capacity by limiting access to inputs or creating uncertainty regarding export regulations.

A frequently mentioned example was the food processing sector's dependence on agricultural inputs. Experts argued that flexible input management policies, including the possibility of using imported raw materials when economically justified, could increase the competitiveness of processed food exports.

Table 8. Institutional barriers affecting food export competitiveness

Institutional constraint	Importance score (0–100)
Exchange rate instability	91.3
Sudden policy changes	88.7
Limited private-sector participation in policymaking	85.4
Export restrictions and administrative barriers	83.9
Difficulty in long-term planning	82.6

4.3.4. Technology and Digital Transformation Pathway

The fourth cluster identified technology upgrading and digital transformation as an important but relatively secondary pathway. Experts acknowledged the importance of automation, data-driven production management, artificial intelligence applications, and Industry 4.0 technologies. However, compared with market development and productivity improvement, technology adoption was perceived as a supporting capability rather than the primary transformation driver.

This finding is consistent with the machine learning results, where machinery imports had a positive but smaller contribution compared with production capacity and productivity.

The results suggest that technological transformation should be capability-driven rather than technology-driven. In other words, digital technologies create value only when integrated with improved management systems, skilled human resources, and market-oriented strategies.

4.4. Integrated Artificial Intelligence-Based Transformation Framework

The final analytical step integrates the findings from machine learning models, SHAP-based explainability analysis, and SOM expert clustering into a unified transformation framework. The quantitative models indicate that, within the fitted predictive framework, historical variation in export performance is most strongly represented by variables related to:

1. food manufacturing capacity;
2. industrial productivity;
3. agricultural value creation;
4. investment capability; and
5. macroeconomic conditions.

These results should be interpreted as identifying variables with substantial predictive relevance rather than establishing that these variables are the causal determinants of export competitiveness.The explainable AI analysis further clarifies that these factors operate through different mechanisms. Production capacity creates export potential, productivity determines competitiveness, agricultural value chains provide supply strength, and economic stability enables long-term planning. The expert-based SOM analysis adds the strategic dimension by identifying how these capabilities can be transformed into practical development pathways. The integration of empirical evidence and expert knowledge results in four interconnected transformation priorities.

Table 9. Integrated AI-based transformation pathways for Iran's food industry

Transformation pathway	Evidence source	Main policy actions
Export market and branding transformation	SOM + expert analysis	Develop national food brands, strengthen international marketing networks, improve market intelligence
Productivity-driven industrial upgrading	XGBoost + SHAP + SOM	Improve operational efficiency, reduce waste, implement quality systems
Institutional and policy transformation	Expert analysis + SHAP	Increase policy stability, strengthen industry participation, reduce uncertainty
Technology-enabled transformation	XGBoost + expert analysis	Promote digitalization, automation, and AI-based industrial management

Source: Research Finding

Overall, the integrated framework demonstrates that Iran's food industry transformation should not be interpreted as a simple expansion of production or a response to external restrictions. Instead, competitiveness requires a coordinated transition from a resource-based and production-oriented structure toward a capability-based, market-oriented, and technology-supported industrial system.

The main contribution of this research lies in moving beyond the traditional identification of export determinants toward the development of evidence-based transformation pathways. While previous studies have mainly focused on explaining what factors affect agricultural or food exports, the proposed AI-driven framework identifies how industrial capabilities can be prioritized and transformed into actionable development strategies.

Accordingly, the findings suggest that the future competitiveness of Iran's food industry depends less on isolated policy interventions and more on the simultaneous development of productive capabilities, international market integration, institutional stability, and adaptive technological capacity. This integrated perspective provides a practical roadmap for policymakers and industrial stakeholders seeking to enhance Iran's role in regional and global food markets.

5. Conclusion and Policy Implications

This study aimed to develop an artificial intelligence-based framework for identifying industrial transformation pathways in Iran's food manufacturing sector. Moving beyond conventional export studies that primarily focus on estimating the determinants of trade performance, this research integrated machine learning models, explainable artificial intelligence (SHAP), and expert-based neural clustering to identify both the historical drivers of competitiveness and the strategic capabilities required for future transformation.

The results demonstrate that export competitiveness in Iran's food industry is primarily associated with internal industrial capabilities rather than external factors alone. The machine-learning models identified food manufacturing output, industrial productivity, and agricultural value creation as the variables providing the strongest predictive contributions to the model's representation of export performance. The SHAP analysis further helped interpret how these variables contributed to individual model predictions and whether their contributions varied across observed conditions. These findings should not be interpreted as establishing causal determinants of export performance; rather, they identify empirical patterns and variables that are strongly informative within the fitted predictive framework.

The integration of expert knowledge through the SOM clustering approach complemented the quantitative findings by identifying feasible transformation priorities from the perspective of industrial stakeholders. The results highlight that Iran's food industry requires a transition from a production-oriented and commodity-based export structure toward a capability-based, market-oriented, and globally integrated manufacturing system. In particular, weaknesses in international branding, market development, policy stability, and productivity management were identified as major constraints preventing the full realization of the sector's export potential.

Based on the findings, the following policy implications are proposed:

- Shift industrial policy from production expansion toward productivity-driven competitiveness.Supporting efficiency improvement, process optimization, quality management systems, and waste reduction should become central components of food industry development strategies.
- Develop export-oriented market capabilities and national food brands. Given Iran's geographical advantages and production potential, greater emphasis should be placed on international marketing, branding strategies, foreign distribution networks, and market intelligence systems.
- Increase policy stability and strengthen private-sector participation in decision-making. Reducing regulatory uncertainty, avoiding sudden trade restrictions, and involving industrial stakeholders in policy formulation are essential for improving long-term investment and export planning.
- Promote agricultural–industrial value chain integration.Strengthening linkages between agricultural producers and food manufacturers can increase domestic value creation, improve supply reliability, and enhance the competitiveness of processed food exports.
- Adopt a capability-based approach to technological transformation.Digitalization, automation, and artificial intelligence applications should be accompanied by

improvements in managerial capabilities, workforce skills, and organizational readiness rather than focusing solely on technology acquisition.

- Design flexible trade and input policies to support export competitiveness. Policies governing access to production inputs should consider international competitiveness objectives and allow firms to optimize sourcing strategies when domestic constraints reduce export potential.

Overall, this research demonstrates that artificial intelligence can serve not only as a predictive instrument but also as a strategic decision-support mechanism for industrial transformation. The proposed framework provides a pathway for policymakers to move from identifying export problems toward designing evidence-based transformation strategies capable of enhancing Iran's position in regional and global food markets.

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Development of a Managerial Antifragility Model in Commercial Firms and Elucidation of Its Impact on Corporate Financial Risk Management

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Abstract

On the one hand, this study serves as an operational roadmap to assist managers in making optimal decisions in high-risk business environments, and on the other hand, it provides a practical framework for policymakers to stabilize and sustain the business environment. The aim of this study is to develop an antifragility model for commercial managers and to examine its impact on corporate financial risk management. This study is applied in terms of purpose and employs a mixed-method (qualitative–quantitative) approach. In the qualitative phase, using Interpretive Structural Modeling (ISM), the dimensions and relationships among antifragility factors were identified and analyzed across three scenarios: economic, political–geographical, and market–competition. In the quantitative phase, Structural Equation Modeling (SEM) was used to test the relationships among variables and to assess the model fit. The statistical population consisted of managers and experts in the financial and commercial sectors. The results indicated that managerial antifragility is a multidimensional and network-based construct, in which factors such as flexible financial management, export market diversification, and product innovation were identified as the most important driving forces across different scenarios. Furthermore, the quantitative results showed that managerial antifragility has a positive and significant effect on corporate financial risk management and explains a substantial portion of its variance. Overall, the findings suggest that antifragility is not merely an individual trait but a strategic and systemic capability in organizational management that can reduce financial risks and create sustainable competitive advantage through financial flexibility, diversification, innovation, and dynamic decision-making.

Keywords: Antifragility, Commercial Managers, Financial Risk Management,

چکیده

این پژوهش با هدف طراحی مدل «پادشکنندگی» برای مدیران بازرگانی و ارزیابی اثر آن بر مدیریت ریسک‌های مالی بنگاه‌ها در شرایط نااطمینانی و بی‌ثباتی اقتصادی تدوین شده است؛ رویکردی که هم‌زمان یک نقشه‌راه عملیاتی برای تصمیم‌گیری مدیران بنگاه‌های تجاری-صنعتی و چارچوبی کاربردی برای سیاست‌گذاران در جهت تثبیت محیط کسب‌وکار فراهم می‌سازد. روش‌شناسی این مطالعه از نوع آمیخته (کیفی کمی) است. در فاز کیفی، با استفاده از روش مدل‌سازی ساختاری تفسیری، ابعاد و پیوندهای پادشکنندگی در سه سناریوی کلیدی «اقتصادی»، «سیاسی جغرافیایی (ژئوپلیتیک)» و «بازار رقابت» استخراج و ساختاربندی شد. سپس در فاز کمی، روابط علی میان متغیرها از طریق مدل‌سازی معادلات ساختاری با جامعه آماری مدیران و کارشناسان ارشد مالی و بازرگانی مورد آزمون و تأیید قرار گرفت. یافته‌ها نشان می‌دهد پادشکنندگی مدیریتی سازه‌ای چندبعدی و شبکه‌ای است که اصلی‌ترین پیشران‌های آن در تمامی سناریوها شامل «مدیریت مالی منعطف»، «تنوع‌بخشی به بازارهای صادراتی» و «نوآوری در محصول» است. همچنین نتایج نشان داد این قابلیت اثر مستقیم، مثبت و معناداری بر ارتقای تاب‌آوری و کنترل ریسک‌های مالی بنگاه دارد. از دیدگاه اقتصاد و مدیریت صنعتی، پادشکنندگی فراتر از تاب‌آوری انفعالی، قابلیتی ساختاری و استراتژیک است که به بنگاه‌های اقتصادی امکان می‌دهد در مواجهه با تکانه‌های کلان ارزی، ژئوپلیتیکی و رقابتی، شوک‌ها را به فرصتی برای بازآفرینی، کاهش ریسک و خلق مزیت رقابتی پایدار تبدیل کنند.

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1. Introduction

In today's complex and high-risk markets, the psychological and behavioral characteristics of commercial managers are recognized as key determinants of firms' financial success (Rцser, 2024). Managerial antifragility defined as the capacity of managers to confront, withstand, and recover from challenging conditions and crises has emerged as a critical factor in mitigating volatility and enhancing the effectiveness of financial risk management (Axenie et al. 2023). Recent studies indicate that managers with higher levels of antifragility are better equipped to make sound decisions under conditions of uncertainty and can control and reduce corporate financial risks through more systematic and structured mechanisms (Lee & Kim, 2025). Despite the significance of this issue, the precise role of managerial antifragility in financial risk management has received limited attention in many traditional financial models and therefore warrants more indepth examination and conceptual modeling (Wang et al., 2025). The term antifragility was first introduced by Nassim Nicholas Taleb in 2012. In his book Antifragile: Things That Gain from Disorder, he argues that some systems benefit from crises and abrupt changes; they grow and improve when exposed to volatility, disorder, stressors, and chaos (Lyu et al., 2024). Such organizations exhibit a strong propensity to engage with risk and ambiguity. It is important to note that antifragility is a broader concept than resilience and robustness. A resilient organization merely endures external shocks and continues along its path without substantial change; by contrast, in antifragile systems, the organization not only avoids capitulation under high pressure and volatility, but also becomes stronger by patterning, learning, and adapting through crises. This principle can be extended to a wide range of phenomena that evolve over time (Rafi et al., 2016). In recent years, particularly following the 2008 financial crisis, this framework has attracted considerable attention from scholars and practitioners. Antifragility is now rapidly expanding as a strategic construct, because its implementation enables institutions not only to stabilize their current position, but also to enhance their standing and secure a larger share of today's intensely competitive international markets by overcoming crises and optimizing organizational routines (Barth & Schreft, 2025).

Within the contemporary business ecosystem, rapid transformations in economic and political arenas, together with shifting market dynamics, have generated substantial risks for commercial activities. Despite access to diverse information channels, a considerable number of firms still lack the capability to anticipate plausible scenarios and to assess their implications for organizational performance. This challenge is particularly evident in export destinations such as Iraq, the United Arab Emirates, and other neighboring countries, where exchangerate volatility, changes in customs regulations, and major political events can fundamentally alter profit margins and business survival within a short period of time (Munoz et al., 2022).

A review of the domestic research literature indicates that the concept of antifragility has largely been overlooked in the field of commerce, with most studies primarily focusing on constructs such as resilience and risk management. Consequently, this issue represents a noteworthy research gap. Accordingly, a fundamental deficiency in this domain is the absence of a structured and practical framework for assessing the antifragility of commercial firms when confronted with diverse scenarios, one that can integrate retrospective data with expert perspectives to accurately identify potential risks and emerging opportunities. The necessity and significance of the present study can therefore be examined from two principal perspectives:

First, to provide a practical tool for managers and decisionmakers in commercial firms to anticipate economic, political, and market scenarios and to evaluate their potential effects on sales, profitability, and supply chains.

- Second, to enhance organizational antifragility by proposing strategies such as market diversification, contractual flexibility, diversified supply networks, and adaptive financial management. Understanding these aspects enables managers and traders to make strategic decisions based on realistic, scenariooriented analyses, allocate resources more efficiently, mitigate the impact of unexpected shocks, and strengthen their competitiveness in both domestic and international markets.

The necessity of this study stems from the growing complexity and volatility of contemporary business environments, where firms need a deeper understanding of how managerial behavioral characteristics shape risk management strategies and organizational responses to uncertainty. Such an understanding is essential for maintaining financial stability, improving decision-making, and enhancing organizational performance under conditions of heightened risk. This issue is particularly relevant in high-risk industries, including finance, energy, and information technology, where managerial decisions can substantially influence firms' exposure to uncertainty and their ability to manage potential disruptions. Identifying the relationship between managerial characteristics and risk management can therefore provide valuable insights for managers, investors, and policymakers seeking to develop more effective and forward-looking approaches to risk management (Sun et al., 2023). Consequently, investigating and modeling the impact of managerial antifragility on financial risk management facilitates the development of behavior-based managerial solutions and addresses extant research gaps in this domain.

Accordingly, the present study serves as an operational roadmap to assist managers in making optimal decisions within high-risk business environments while simultaneously providing a practical framework for policymakers to stabilize and sustain the business environment. To achieve this mission, the following objectives are delineated and proposed:

Identifying the fundamental components (including crises, strategic decisions, and relevant indicators).

- Determining the causal relationships among the identified components.
- Constructing the Direct Mode of Dependency Matrix (DMDM).

- Analyzing and evaluating the extent to which crises and corrective actions influence the level of antifragility.
- Formulating actionable strategies to enhance antifragility capacity in commercial firms, drawing on the results of scenario analysis within the Interpretive Structural Modeling (ISM) framework.
- Validating the antifragility scenarios in commerce and their effects on corporate financial risk management through Structural Equation Modeling (SEM).

2. Theoretical Literature

Antifragility is a concept that extends beyond resilience and was first introduced by Taleb (2012). Unlike resilience, which focuses on an organization's ability to recover and return to its precrisis state, antifragility refers to the capacity for growth, advancement, and the strategic utilization of volatility and disruptions. The theoretical foundations of organizational antifragility are grounded in the principle that firms operating in turbulent and highrisk ecosystems, such as the environment of international trade and the constraints imposed by sanctions, should not merely focus on absorbing shocks and resisting disturbances. Rather, they should transform these threats into opportunities for organizational learning, innovation creation, and sustainable development (Guo, 2025).

The core components of this framework include diversification (in resource allocation, market penetration, and network development), flexibility (in organizational structure, contractual arrangements, and strategic planning), organizational learning and innovation (leveraging trialanderror approaches to improve performance), as well as synergy and networking (establishing supportive interactions at both intra and interorganizational levels). Relying on such a conceptual framework enables commercial firms to confront major economic and political risks and market volatility not only by ensuring their survival but also by significantly strengthening their competitive position and market advantage (Jin & Lee, 2025).

2-1. Hypothesis Development

Economic Scenarios

During periods of economic recession, the decline in aggregate demand leads to a significant reduction in cash inflows, thereby increasing liquidity risk and threatening the financial structure of firms. Under such conditions, fixed costs remain uncovered, exerting additional pressure on financial stability. Antifragile firms, however, maintain positive cash flow (CF>0)(CF > 0)(CF>0) through market portfolio diversification and dynamic pricing strategies. This flexibility enables them to capitalize on the exit of weaker competitors and expand their market share (Ivanov & Dolgui, 2020). Severe exchange rate volatility heightens market risk, particularly currency risk, and renders profit margins and cost structures highly unpredictable. Organizations that employ hybrid hedging strategies and flexible currency contracts can not only protect the value of their assets but also benefit from arbitrage opportunities created by currency fluctuations by incorporating optionality into their international financing strategies (Madura, 2020). Persistent inflation implies a continuous increase in operational costs and a growing demand for working capital, which directly heightens the risk associated with declining purchasing power (Bekaert & Wang, 2010). Within an antifragile framework, the strategic conversion of excess liquidity into tangible assets, particularly critical raw materials, can serve as an effective mechanism for mitigating exposure to inflationary pressures. Furthermore, employing dynamic optimization approaches to resource allocation enables firms to adjust investment decisions in response to changing economic conditions, thereby reducing the adverse effects of inflation on asset returns and enhancing the firm's capacity to benefit from market volatility. (Cieslak & Pflueger, 2023). Accordingly, the following hypothesis is proposed:

H1: *Economic scenarios*, specifically market diversification and pricing flexibility, have a significant effect on corporate financial risk management.

Political and Geopolitical Scenarios

The imposition of sudden trade restrictions significantly elevates concentration risk and can push revenue streams to the brink of default or bankruptcy. Strategies such as geographical diversification of target markets and the design of modular value chains reduce a firm's systematic dependence on any single market and safeguard its capital structure against geopolitical shocks (Gereffi, 2020). Such crises often degrade logistical infrastructure, thereby increasing operational and credit risks and prolonging the cash conversion cycle. Employing decentralized distribution networks, regional strategic warehouses, and the ability to rapidly reroute shipments creates systemic resilience and prevents the erosion of working capital (Sodhi & Tang, 2021). Increases in tariffs or changes in freetrade regulations generate unexpected costs and compress profit margins. Establishing contractual flexibility, for instance, through tariffrisk sharing clauses, and agility in switching sourcing alternatives allow firms to distribute financial risk across the supply chain and manage cost structures more effectively (Handley et al., 2020). Accordingly, the following hypothesis is proposed:

H2: *Political and geopolitical scenarios*, including exportmarket diversification and contractual flexibility, have a significant impact on corporate financial risk management.

Market and Competitive Scenarios

The entry of lowcost competitors directly threatens profitability risk and places downward pressure on return on equity. Rather than engaging in price wars, antifragile organizations create new sources of value through agile product innovation and the development of dynamic capabilities, thereby shifting toward market segments characterized by relatively inelastic demand (Teece, 2018). Such competitive shifts increase the risk of inventory obsolescence and necessitate the recognition of asset impairment charges in financial statements. The implementation of agile methodologies, such as smallscale market testing, together with the application of real options theory, minimizes sunk costs and rapidly reallocates capital toward projects with a positive net present value (NPV>0)(NPV > 0) (NPV>0) (Trigeorgis & Reuer, 2017). Supply disruptions lead to production stoppages and can drive cash inflows to zero while financial and fixed costs remain unchanged. Strategies centered on the development of a multisourcing supplier base and the use of digital twins for realtime supply chain monitoring prevent bottlenecks and ensure the continuity of financial operations (Craighead et al., 2020). Accordingly, the following hypothesis is proposed:

H3: *Market and competitive scenarios*, including product innovation and flexible branding, have a significant effect on corporate financial risk management.

Independent Variables: Commercial Antifragility Indicators

- Economic scenarios
- Political and geopolitical scenarios
- Market and competitive scenarios

Dependent Variable: Corporate financial risk management

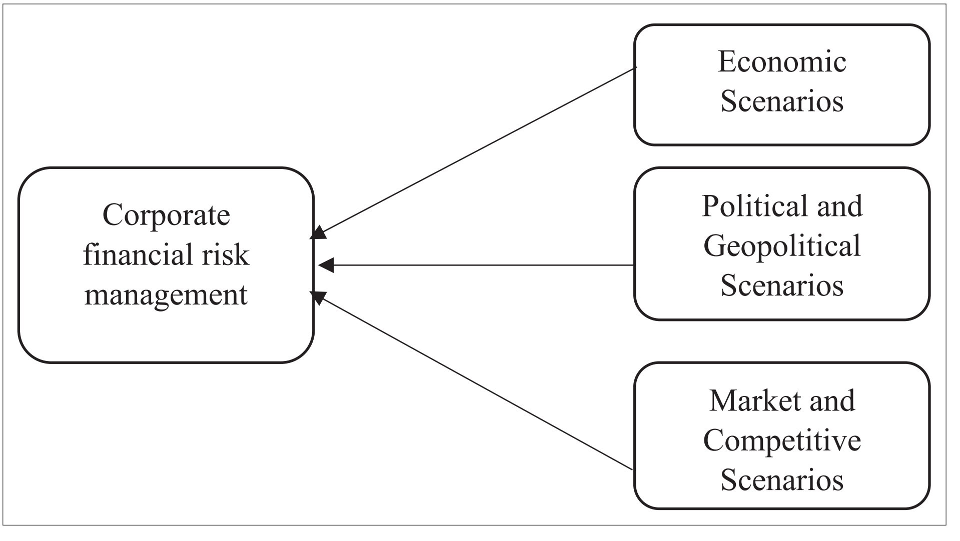

Figure 1. Conceptual Model of the Study Derived from the Qualitative Phase of the Research

2-2. Literature Review

The concept of antifragility, as a paradigm that goes beyond resilience and robustness, has in recent years attracted considerable attention among scholars in the fields of management and economics (Ivanov, 2020). Nevertheless, a review of the existing literature indicates that both domestic and international studies have predominantly focused on macrolevel notions of antifragility within supply chains or complex systems (Khodaparast et al., 2023). Empirical works that specifically seek to explicate a “managerial antifragility model in commercial firms” and to examine its direct impact on “corporate financial risk management” are extremely limited and rare.

This paucity of research highlights a significant scholarly gap in understanding how managers can transform financial volatility and shocks into opportunities for growth. This gap further underscores the necessity and originality of the present study. Accordingly, in this section given the scarcity of fully aligned studies. we review and elaborate on those domestic and international works that are most closely related, in conceptual terms, to the variables of this research (including organizational resilience, managers’ dynamic capabilities, enterprise risk management under conditions of uncertainty, and the generic applications of antifragility in finance). This review is intended to provide the theoretical foundations required to develop the proposed research model. Some of these studies are presented below.

Khodaparast et al. (2023) examined supply chain antifragility in the textile industry by identifying and prioritizing the factors that enable supply chains to improve their performance when exposed to uncertainty, disruptions, and external stressors. Using the Best-Worst Method (BWM) and the Combined Compromise Solution (CoCoSo), the study evaluated the relative importance of antifragility-related factors and provided a structured approach for prioritizing strategic responses to supply chain disruptions. The findings highlight the importance of identifying critical stressors and developing capabilities that allow supply chains not merely to withstand disruptions, but to adapt and improve through exposure to uncertainty. This perspective supports the broader view of antifragility as a strategic capability that enables organizations to transform environmental turbulence and disruption into opportunities for adaptation and performance improvement. Corvello et al. (2024) examined antifragility in 181 innovative Italian start-ups and found that intangible resources, tangible slack resources, and absorptive capacity contribute to the development of organizational antifragility. Their findings indicate that antifragility enables start-ups not merely to survive crises but to adapt, improve their position, and achieve better performance following disruptive events. Moradi and Seyghali (2025) conducted a study titled “Examining the Role of Antifragile Business Processes in Explaining the Impact of Digital Transformation on Enterprise Risk Management.” The findings reveal that firms designing their business processes in an antifragile manner are not merely resistant to environmental disruptions but actively leverage volatility and crises as opportunities for growth and organizational learning. The novelty of this study lies in integrating three relatively distinct yet complementary domains, digital transformation, antifragility, and enterprise risk management, and proposing a conceptual framework for the intelligent resilience of organizations in the digital era. Based on the results, the authors recommend that business managers enhance organizational capabilities to address emerging risks and rapid environmental changes by prioritizing datadriven strategies and digitally redesigning core processes.

3. Research Methodology

3-1. Qualitative Phase

The present study is applied in orientation and employs a mixedmethods design (qualitative–quantitative), aiming to examine the level of business antifragility in the face of various economic, political, and market scenarios. To this end, a combination of secondary data and expert insights was utilized.

In the first step, through monitoring historical documents and timeseries data (such as GDP growth rates, inflation, exchangerate volatility, and foreign trade indicators), plausible economic scenarios, such as international recession and domestic inflation, were identified. Subsequently, geopolitical and policy developments (including trade sanctions, conflicts in target export markets, and changes in customs procedures) were analyzed with reference to official sources such as the Customs Administration and the Trade Promotion Organization. Furthermore, in order to analyze competitive market scenarios, documents such as sales trends, competitors' reports, and changes in customer preferences were examined. It should be noted that the extraction and selection of indicators and subindicators were carried out using the Delphi method and the dimensions of the Interpretive Structural Modeling (ISM) questionnaire. Finally, after screening and ranking the criteria, the ISM technique and MicMac software were employed to uncover causal relationships among the variables and to analyze the scenarios. Accordingly, the operational steps for administering and analyzing the questionnaires were designed as follows:

- **Firstround questionnaire:** In the first round, experts with a minimum of 10 years of professional experience, at least 30 years of age, and holding at least a master's degree were asked to rank each of the identified economic, political and geopolitical, and market and competitive indicators.
- **Secondround questionnaire:** In the second round, all criteria and subcriteria of each main scenario selected from the first questionnaire were weighted based on the interpretive structural modeling matrix. In this stage, experts were requested to complete the matrix according to its predefined scales.

Collection and Analysis of Empirical Data and Integration with Expert Judgments

Following data collection, industry and market experts were engaged to estimate the probability of occurrence of each scenario and the magnitude of its impact on business operations. The results of structured interviews with 30 experts in the field of commerce are presented in the subsequent section. The following scenarios were considered, and the corresponding data were ultimately compiled as inputs for the scenario analysis model.

Table 1. Economic Scenarios

Scenario	Description	Potential Impact on Business	Related Antifragility Indicator
Global economic recession	Decline in external demand due to economic downturn in target markets (e.g., Iraq, the UAE)	Reduced sales and profitability	Market diversification; pricing flexibility
Exchange rate volatility	Sudden increase or decrease in the value of the U.S. dollar or the Iranian rial	Higher import costs and fluctuations in selling prices	Contract diversification; flexible financial management
High domestic inflation	Rising costs of packaging, transportation, and warehousing	Reduced profit margin	Cost optimization; flexible inventory expansion

Table 2. Political and Geopolitical Scenarios

Scenario	Description	Potential Impact	Antifragility Indicator
Export sanctions	Restriction of exports to the target country	Loss of part of the market	Diversification of export markets; flexible contracts
Unrest or war in the destination country	Disruption in logistics and the market	Delivery delays; loss of customers	Multiple transportation routes; regional warehouses
Changes in customs regulations	Increased tariffs or new regulatory requirements	Higher export costs and longer processing time	Operational and contractual flexibility

Table 3. Market and Competitive Scenarios

Scenario	Description	Potential Impact	Antifragility Indicator
Entry of a new lowprice competitor	Reduction in market share and pressure on prices	Decline in sales and profit margins	Product innovation; flexible branding
Change in consumer preferences	Decreased demand for the core product	Decline in sales	Development of alternative products; smallscale market testing
Sudden disruption of a key supplier	Product shortage	Supply chain disruption	Diversified supplier network; alternative contracts

- Economic variables were calculated quantitatively based on numerical indicators such as the exchange rate, inflation, and gross domestic product (GDP).
- Political/geopolitical variables were measured dichotomously (occurrence/nonoccurrence) with reference to factors such as sanctions, political unrest, and regulatory changes.

- Market and competitive variables were also evaluated as binary events (occurrence/nonoccurrence), including entry of new competitors, changes in consumer preferences, and supply disruptions.
- The Antifragility Index was assessed through the FailureLearning Index (FLI), which measures the extent to which an organization or manager, after experiencing a shock or crisis, revises decisions and improves overall performance. The simple and practical formula is presented as follows:

$$\text{Failure–Learning Index (FLI)} = \frac{\text{Number of revised decisions}}{Total\ of\ shocks}$$

- Number of revised decisions: Refers to the actions, strategies, or decisions that were modified or improved following a failure or shock.
- Total number of crises: Refers to the number of stressful or unpredictable events that have occurred.

3-2. Quantitative Phase

In this stage, following the definition of the scenarios and the proposed model, the model was validated and its explanatory power regarding the financial performance of firms was examined. The statistical population consisted of financial managers and business owners in Tehran. Due to the large size of the population, the questionnaire was distributed using a stratified sampling method, based on the results of the prior qualitative study that had initially conceptualized antifragility within the context of commerce. The sample size was determined to be 384 respondents using the Cochran formula. Data were collected through a researcherdeveloped questionnaire designed to measure business antifragility, along with adapted and localized indicators for enterprise risk management, developed on the basis of the conceptual model and theoretical literature. After conducting descriptive analysis of the data, Structural Equation Modeling (SEM) using SmartPLS was employed to test the research hypotheses and evaluate the proposed model. Additionally, SPSS software was used for descriptive and complementary statistical analyses. The questionnaire utilized in this study was based on an instrument previously developed by Moradi and Seyghali (2025), whose validity and reliability had already been established in their research.

Measurement of Corporate Financial Risk Management Variable

In this study, the variable of corporate financial risk management is measured using a questionnaire based on a five-point Likert scale, designed to assess the processes of identifying, evaluating, controlling, monitoring, and responding to financial risks. This questionnaire captures the perceptions of managers and financial experts regarding the effectiveness and comprehensiveness of financial risk management in the firms under investigation. The items in this instrument are structured to cover the key dimensions of financial risk management, including the systematic identification of financial risks, the existence of financial controls to mitigate such risks, the continuous monitoring of risk exposure, and planning for crisis situations. The validity and reliability of this questionnaire have been confirmed in previous studies, and in the present research, they will also be evaluated through factor analysis and internal consistency indicators, including Cronbach's alpha and Composite Reliability (CR) (Mikes & Kaplan, 2014).

Measurement of the Antifragility Variable

This instrument was developed based on the author's empirical study, Moradi (2025), and represents the first antifragility assessment form in the field of commerce, constructed around three major scenarios: economic, political–geographical, and market–competitive. Accordingly, the questionnaire was designed because of these three key dimensions: economic, political–geographical, and market–competitive. This instrument was first examined and analyzed in Moradi (2025), presented at the Third Conference on Engineering and Management of Organizational Processes.

Instruction:

Please indicate your level of agreement with each statement using the following scale:

1 = Strongly disagree
2 = Disagree
3 = Neither agree nor disagree
4 = Agree
5 = Strongly agree

Note: Items marked with ® are reverse-coded and should be scored in the opposite direction during data analysis.

Administration, Scoring, and Recommended Tests:

1) Scoring

First, all items marked with ® are reversecoded.

- The mean or sum of the items within each subscale is computed as the subscale score.
- The mean or sum of the subscale scores is then computed as the overall "Commercial Antifragility" score, if required.

The interpretation of overall antifragility scores is presented in Table 4.

Table 4. Interpretation of Overall Antifragility Scores

Overall Mean (Three Dimensions)	Interpretation	Recommended Action
4.1 – 5.0	Antifragile	The organization benefits from crises and grows through them. Focus on stabilizing learning and scalability.
3.1 – 4.0	Resilient with growth potential	The organization can survive crises but derives limited benefit from volatility.
2.1 – 3.0	Semifragile	A redesign of financial and contractual systems is required. Emphasize supply diversification and innovation.
1.0 – 2.0	Fragile	The likelihood of collapse under economic and political shocks is high. A fundamental redesign of the business model is essential.

4. Findings

4-1. Demographic Information of Experts

The results indicate that the expert sample consisted of 30 individuals, of whom 24 were male and 6 were female. The average age of the participants was 45.8 years. The mean age of chief executive officers within the sample was slightly higher than the overall average, reaching 46.8 years. Regarding educational background, the highest frequency corresponded to the field of Business Management, with 15 participants. This was followed by Industrial Management, Accounting, Public Administration, and Law. In terms of educational level, the Master's degree category showed the highest representation with 21 individuals, while Doctoral degree holders ranked second. This demographic and educational composition reflects the emphasis of the organizations under study on managerial expertise and a high level of academic knowledge. Such characteristics can play an essential role in enhancing strategic decisionmaking, crisis management, and the management of commercial scenarios.

4-2. Estimation of Scenarios in the Interpretive Structural Model

Step 1: Construction of the Structural SelfInteraction Matrix (SSIM)

In this step, the experts compare the criteria pairwise and respond to the pairwise comparisons using the following symbols. For each pair of criteria, one of the letters V, A, X, O is assigned according to the definitions below:

- **V:** The factor in row i leads to (helps achieve) the factor in column j.
- **A:** The factor in column j leads to (helps achieve) the factor in row i.
- **X:** Both the row and column factors lead to each other (factors i and j have a bidirectional relationship).
- **O:** There is no relationship between the row and column factors.

Step 2: Derivation of the Initial Relationship Matrix

Following the identification of the relevant variables and the assessment of their interrelationships by the expert panel, an initial relationship matrix was constructed for each of the three analytical scenarios. In this stage, the judgments obtained from the experts were converted into numerical values representing the strength of the relationship between each pair of variables. The relationships were coded using a four-point scale, in which 0 indicates no relationship, 1 indicates a weak relationship, 2 indicates a moderate relationship, and 3 indicates a strong relationship. Accordingly, the value assigned to cell (ij) represents the assessed influence or relationship of variable (i) on variable (j). The diagonal elements were assigned a value of zero because a variable was not considered to exert a direct relationship on itself.

Based on this procedure, three initial relationship matrices were developed corresponding to the economic, political–geographical, and market and competitive scenarios. The resulting matrices preserve the direction and intensity of the relationships identified by the experts and provide the input required for the subsequent stages of the ISM/MICMAC analysis. The initial matrices for the three scenarios are presented in Tables 5–7.

Table 5. Initial Reachability Matrix for the Economic Scenario

	1: Price	2: Finance	3: Costs	4: Inventory
1: Price	0	2	3	2
2: Finance	3	0	3	2
3: Costs	3	3	0	3
4: Inventory	2	1	2	0

Table 6. Initial Reachability Matrix for the Political–Geographical Scenario

	1: Diversification	2: Contracts	3: Transportation	4: Warehousing	5: Contractual Terms
1: Diversification	0	3	3	3	3
2: Contracts	1	0	3	2	2
3: Transportation	1	1	0	2	2
4: Warehousing	3	2	2	0	1
5:Contractual Terms	1	2	2	3	0

Table 7. Initial Reachability Matrix for the Market and Competitive Scenario

	1: Innovation	2: Branding	3: Product Development	4: Market Testing	5: Contract
1: Innovation	0	3	3	3	3
2: Branding	2	0	3	3	3
3:Product Development	2	1	0	2	2
4: Market Testing	2	2	1	0	2
5: Contract	2	2	2	1	0

Step 3: Consistency Adjustment of the Reachability Matrix

In the third step, the initial reachability matrix must be refined and made consistent. This consistency is achieved by adding transitive (secondary) relationships that may not appear explicitly in the initial matrix. After these adjustments, the intensity of influence among variables can be examined. It should be noted that the numerical values in each row represent the influence exerted by that variable on others, while the values in each column reflect the dependence of that variable on others. The consistency rule is assessed as follows:

If

- i,j=1 i, j = 1 i,j=1
- j,k=1 j, k = 1 j,k=1

then

- i,k=1 i, k = 1 i,k=1

In other words, if Criterion A influences Criterion B, and Criterion B influences Criterion C, then Criterion A must also influence Criterion C. Due to the considerable length of the finalized consistency matrices, they are not presented in the article. Instead, only the key outputs are reported.

Step 4: Determining the Levels of Variables

Following the construction of the final reachability matrix, the hierarchical levels of the identified variables were determined using the reachability set, antecedent set, and their intersection. For each iteration, the reachability and antecedent sets were identified for all remaining variables, and the intersection between the two sets was subsequently calculated. Variables for which the reachability set was identical to the intersection set were assigned to the corresponding hierarchical level and removed from the subsequent iteration. This procedure was repeated until all variables were assigned to a hierarchical level. The resulting levels provided the basis for constructing the final ISM hierarchical structure and identifying the relative position of the variables within the model. At the end of the calculations for each scenario, the final levels and the accuracy percentage of each scenario are determined. A summary of these results is presented in Table 8.

Table 8. Percentage of Variable Levels

Variable	Reachability Set	Antecedent Set	Intersection	Level
Diversification	1, 3, 10, 11, 12	1, 2, 3, 4, 5, 6, 7, 8, 9, 13, 14	1, 3	III
Price Flexibility	2, 3, 5	2, 4, 5, 6, 9	2, 5	II
Contract Diversification	3, 10, 12	1, 2, 3, 4, 5, 6	3	I
Flexible Financial Management	4, 5, 6	2, 4, 5, 6	4, 5, 6	III
Cost Optimization	5, 6	2, 4, 5, 6, 9	5, 6	II
Flexible Inventory Increase	6	4, 5, 6, 7, 8	6	I
Multiple Transportation Routes	7, 8	7, 8, 9	7, 8	II
Regional Warehouses	8	7, 8	8	I
Operational Flexibility	9, 10, 12	4, 7, 9	9	III
Product Innovation	10, 11, 12	1, 3, 9, 10, 11	10, 11	II
Branding	11	1, 10, 11	11	I
Substitute Product Development	12	1, 3, 9, 10, 12	12	I
Small Market Testing	13, 10	13, 14	13	III
Diversified Supplier Network	14, 7, 8	14	14	I

Step 5: Drawing the Interaction Network

In this stage, based on the hierarchical levels of the criteria obtained from the ISM model and the relationships identified among them, the interaction network is constructed. The first level is considered the most dependent level, while the final level represents the most influential level. Accordingly, the research model can be illustrated for each scenario in terms of the influence power and dependence degree of each criterion. As an example, the influence–dependence diagram of the economic scenario, which depicts the relative influence and dependence of variables, is presented. The positioning of variables in this diagram can be interpreted as follows in the figure 2. The influence–dependence diagram of the economic scenario, which illustrates the influence power and dependence of the variables.

- Price flexibility: This variable is usually the result of financial management policies and cost optimization strategies; however, it can also influence sales and inventory levels. Therefore, it exhibits high dependence and moderate influence.
- Flexible financial management: This acts as a key enabler through mechanisms such as flexible budgeting (cost reduction) and working capital control (inventory management). This criterion has high influence power and low dependence.
- Cost optimization: This originates from financial management but also affects pricing decisions and inventory levels. Therefore, it demonstrates relatively high influence and moderate dependence.

- Flexible inventory increase: This variable is highly dependent on financial management and pricing policies. On its own, it has a limited strategic role; however, it holds operational importance within the supply chain. Thus, it has high dependence and low influence power.

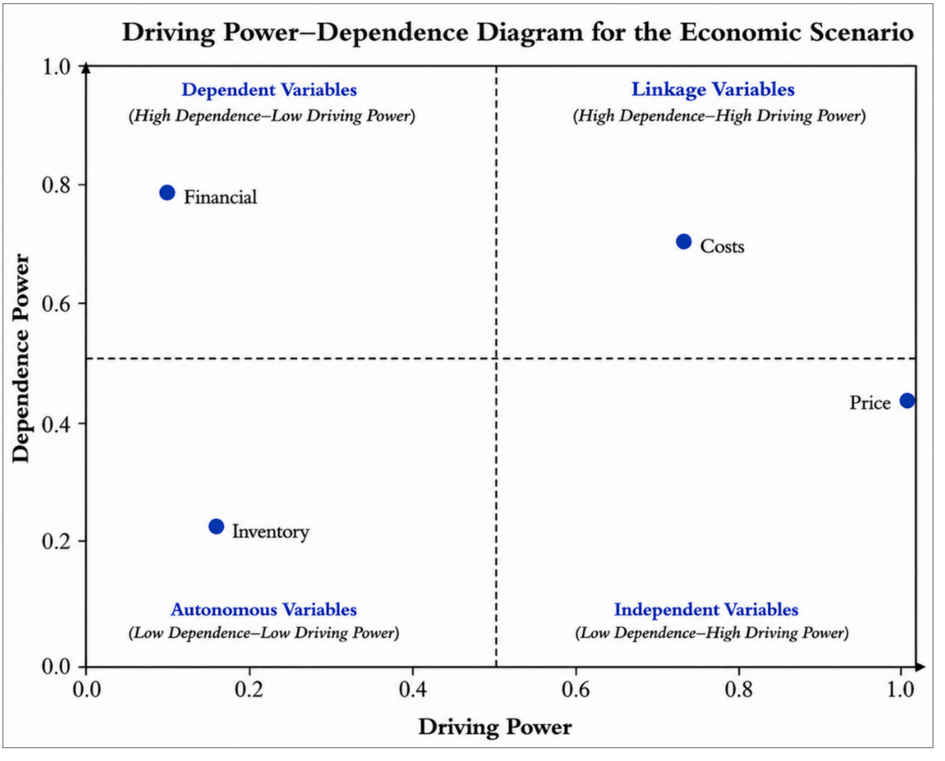

Figure 2: Dependence-Influence Diagram of the Economic Scenario

- The influence–dependence diagram of the political–geographical scenario in the figure 3, can likewise be illustrated in terms of power of influence and degree of dependence.
- Export market diversification: This requires flexible contracts, multiple transportation routes, and regional warehouses; however, it acts as the main driving factor (driver) itself.
- Flexible contracts: These provide the foundation for entering new markets and achieving operational flexibility. They exhibit high influence and moderate dependence.
- Multiple transportation routes: These serve as a supporting tool for exports and access to diversified markets. They depend on market decisions and contractual arrangements, but they affect regional warehouses and operational flexibility.

- Regional warehouses: These are highly dependent on transportation routes and contractual structures. They have relatively low influence and function mainly as a dependent factor.
- Operational and contractual flexibility: This is both an outcome of flexible contracts and a facilitator of diversified markets. It plays a linkage role.

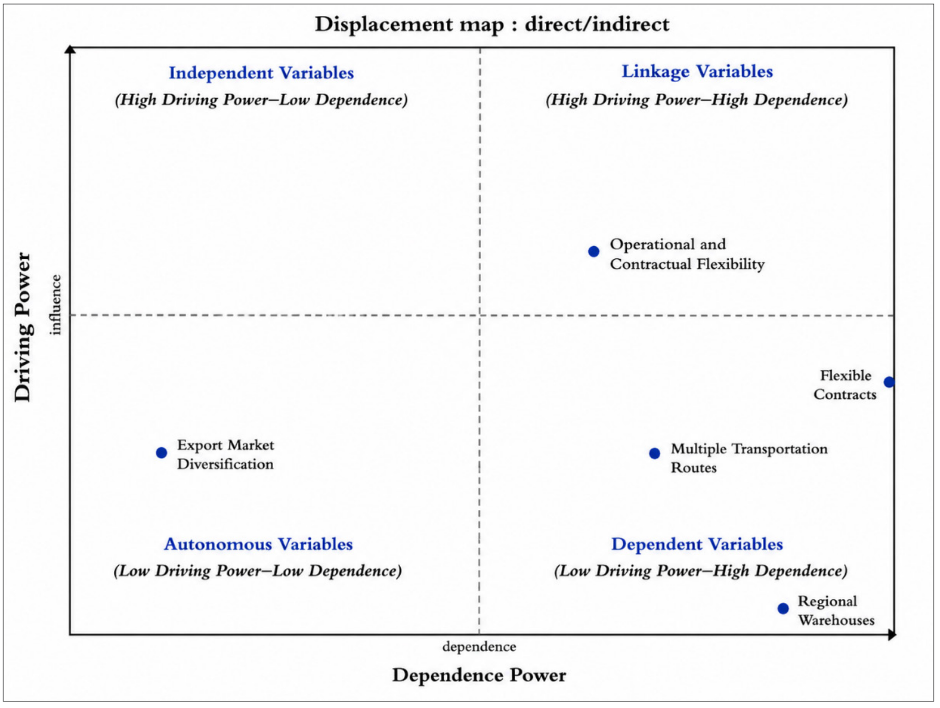

Figure 3: Dependence-Influence Diagram of the Political and Geographical Scenario

The influence–dependence diagram of the market and competition scenario in figure 4, can also be illustrated in terms of influence power and degree of dependence.

- Product innovation: This is the starting point of competition; without innovation, sustainable branding or the development of alternative products is not possible. Therefore, it acts as the main driver.
- Branding: This is the result of innovation and market testing, but it can also influence product development and alternative contractual arrangements. It therefore has moderate-to-high influence and moderate dependence.
- Development of alternative products: This is a function of innovation and market testing and, in a sense, serves as a defensive strategy in competition. Thus, it plays a linkage role.
- Small-scale market testing: This is highly dependent on product innovation and

serves as a prerequisite for branding and product development. On its own, it has low influence and functions as a dependent factor.

- Alternative contracts: These are usually the result of strong innovation and branding, enabling the firm to establish agreements with new partners. Therefore, they function as a dependent factor.

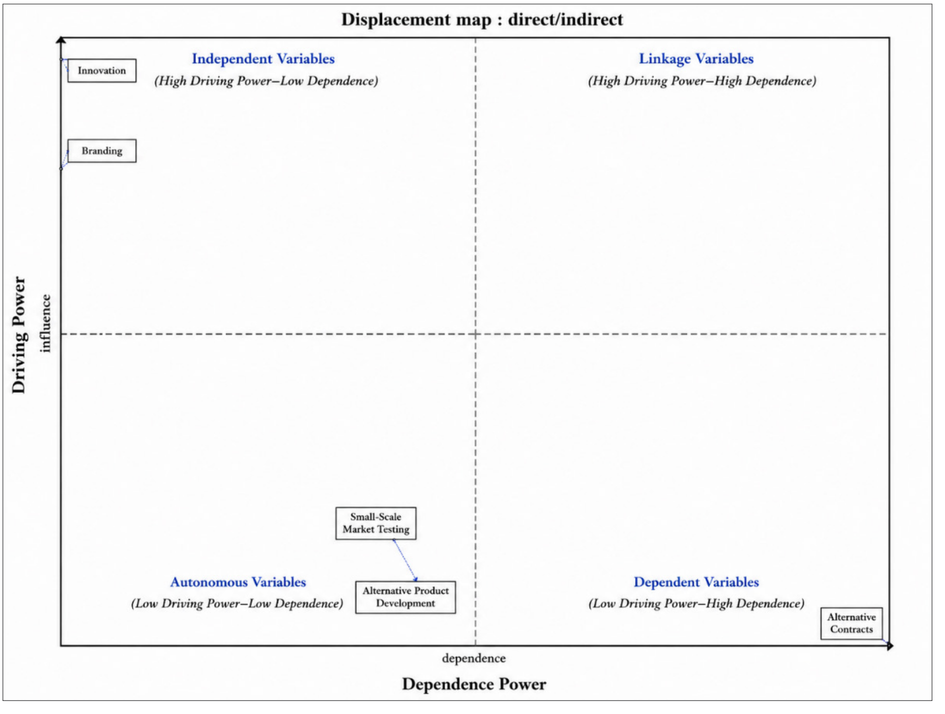

Figure 4: Dependence-Influence Diagram of Market and Competition Scenarios

4-3. Model Validation Using the Structural Equation Modeling (SEM) Approach

4-1. Demographic Information

The results indicate that the sample population consists of 384 individuals, including 227 males and 157 females. The average age distribution of the respondents is 59. The concentration of chief executive officers in the sample is slightly above the overall average, with the average age of CEOs ranging between 35 and 45 years. In terms of organizational position, the largest group of respondents holds the position of Chief Executive Officer (CEO), with a frequency of 93. This is followed by production specialists, IT managers, accountants, and sales managers. Furthermore, regarding work experience, many respondents are active in the financial and commercial sectors, accounting for 42.4 percent of the total respondents.

42. Descriptive Statistics

The results of descriptive statistics show that the variable Corporate Financial Risk Management has the lowest mean value, indicating the relative distribution of respondents' answers across this dimension. The skewness and kurtosis values further confirm that data distribution is normal: skewness coefficients for all variables fall within the range of –3 to +3, and kurtosis values for all components are also within the same acceptable range (–3 to +3). Therefore, it can be concluded that the distribution of data for all variables is statistically normal.

Table 9. Descriptive Statistics of the Variables (Source: Researcher's findings)

		Economic Scenarios	Political and Geopolitical Scenarios	Market and Competitive Scenarios	Corporate financial risk management
N	Valid	384	384	384	384
	Missing	0	0	0	0
Mean		4.093	3.940	3.814	3.809
Median		4.083	4.00	3.800	3.900
Std. Deviation		.697	.729	.7665	.7972
Skewness		-.775	-.394	-.228	-.252
Kurtosis		1.131	.157	-.095	-.346
Minimum		1.0	1.0	1.0	1.0
Maximum		5.0	5.0	5.0	5.0

Given the exploratory nature of the proposed managerial antifragility model and the predictive orientation of the study, Partial Least Squares Structural Equation Modeling (PLSSEM) was employed. PLSSEM is particularly suitable for complex models with newly developed constructs and formative or reflective measurement structures. Furthermore, the relatively large sample size (n = 384) ensures sufficient statistical power for path estimation and bootstrapping procedures. The sample size of 384 respondents exceeds the minimum requirement for structural equation modeling and satisfies the 10times rule recommended for PLSSEM.

4-3. Evaluation of the Model Based on Measurement Criteria

The values presented in Table 10 indicate that the measurement instrument used in this study enjoys an acceptable level of reliability. As observed, the composite reliability coefficients for all constructs are above 0.70.

Table 10. Evaluation of the Model Based on Measurement Criteria (Source: Researcher's findings)

	Cronbach's Alpha	Composite Reliability	Average Variance Extracted (AVE)
Corporate financial risk management	0/915	0/929	0/568
Economic Scenarios	0/867	0/891	0/506
Market and Competitive Scenarios	0/898	0/909	0/595
Political and Geopolitical Scenarios	0/869	0/881	0/568

The results showed that the square root of the AVE values for the latent variables, located on the main diagonal of the matrix, were greater than the corresponding inter-construct correlation values. Therefore, it can be concluded that the discriminant validity of the research model is established at an acceptable level.

Table 11. Correlation Values Based on the Fornell and Larcker Criterion (Source: Researcher's findings)

	Corporate financial risk management	Economic Scenarios	Market and Competitive Scenarios	Political and Geopolitical Scenarios
Corporate financial risk management	0/754			
Economic Scenarios	0/517	0/711		
Market and Competitive Scenarios	0/746	0/679	0/771	
Political and Geopolitical Scenarios	0/718	0/636	0/751	0/753

4-4. Evaluation of the Model Based on Structural Criteria

Since the acceptance or rejection of hypotheses is determined based on the significance of path coefficients, we examined the significance values illustrated in Figures 2 and 3. The factor loadings for all variables are above 0.20, indicating acceptable levels. Conversely, if the factor loadings for any variable were below 0.20, it would suggest a weak relationship. To confirm or reject the hypotheses, the t-statistics were used, as presented below. As shown in Figure 3, the t-statistic values for all paths exceed 1.96, indicating that the hypotheses are supported and confirmed.

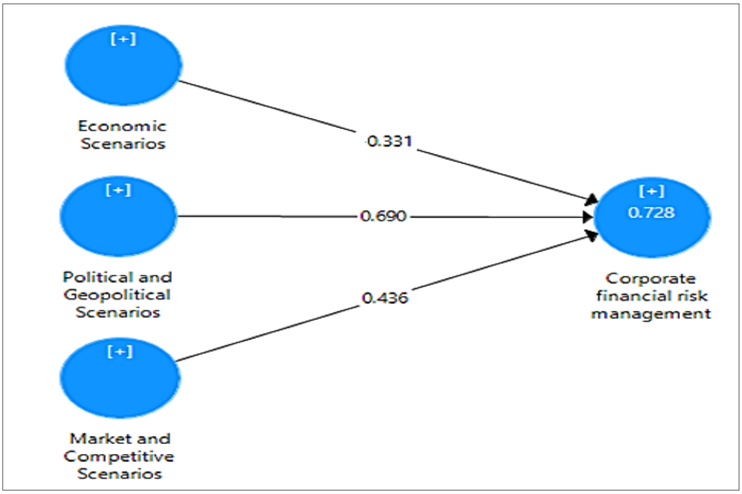

Figure 2. Factor Loadings Results of the Measurement Model in Standardized Coefficients (Source: Researcher's findings)

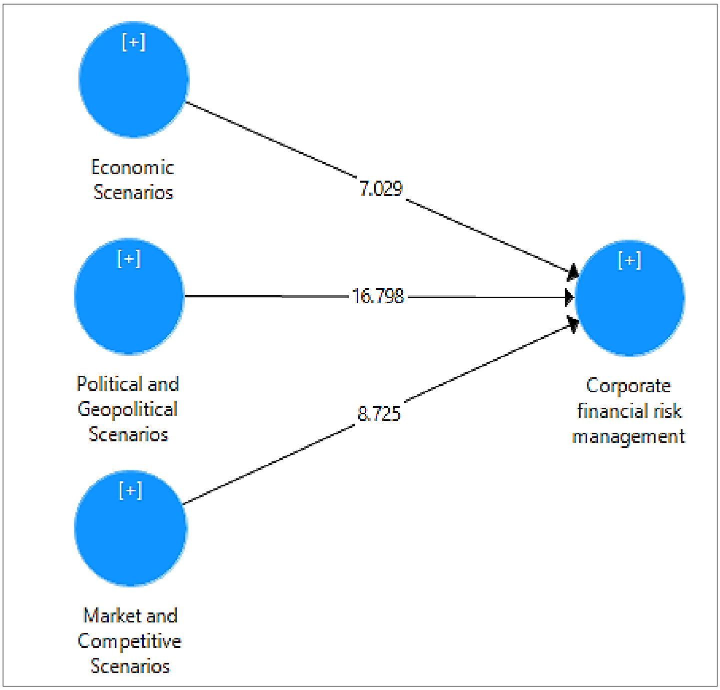

Figure 3. Factor Loadings Results of the Measurement Model in Significance Coefficients (Source: Researcher's findings)

As shown in Table 12, the values for the exogenous variables in this study are above 0.25, indicating a strong model fit.

Table 12. Structural Model Fit Indices (Source: Researcher's findings)

	R Square	f Square	Redundancy	Q2
Corporate financial risk management	0/726	0/728	0/819	0/407

4-5. Evaluation of the Model Based on Overall Fit Criteria

The Standardized Root Mean Square Residual (SRMR) is one of the well-known goodness-of-fit indices in structural equation modeling. Its value ranges from 0 to 1, where values less than 0.08 (and in some references less than 0.05) indicate a good model fit. The results presented in Table 13 demonstrate a strong model fit according to the SRMR criterion. These values indicate a good overall fit of the estimated model, as the SRMR values for both the saturated and estimated models are below the commonly accepted threshold of 0.08.

Table 13. SRMR Index (Source: Researcher's findings)

Indicator	Saturated Model	Estimated Model
SRMR	0.073	0.079
d_ULS	23.302	26.313

5. Discussion and Conclusion

The results of the qualitative section of the study indicated that antifragility in commercial management possesses a multidimensional and network-based nature, in which economic, political, geographical, market, and competitive factors interactively influence an organization's ability to cope with risks and crises. The ISM model analysis and the dependence–driving power diagrams revealed that certain variables function as fundamental driving forces, while others are primarily influenced by managerial decisions and macro-level policies. These findings suggest that organizational antifragility is not merely limited to reacting to crises; rather, it requires the development of structural, financial, and strategic mechanisms capable of strengthening organizations under conditions of uncertainty. Within the economic scenario, "flexible financial management" was identified as the most influential driving factor. This finding demonstrates that managers' capabilities in flexible budgeting, working capital control, and cost management constitute the foundation of other organizational antifragile capabilities. Organizations with more flexible financial structures are better able to implement dynamic pricing, inventory control, and rapid responses to market fluctuations. This finding is consistent with Taleb's antifragility theory, which argues that antifragile systems must possess the capacity to absorb shocks and transform environmental pressures into opportunities. Furthermore, the findings align with studies on financial resilience and organizational crisis management, which emphasize financial flexibility as a key determinant of organizational survival and growth in unstable economic environments. In the political and geographical scenario, "diversification of export markets" and "flexible contracts" demonstrated the highest driving power. These findings indicate that under conditions of sanctions, political instability, and supply chain disruptions, organizations that reduce their dependence on limited markets and routes are more likely to succeed. Market diversification and the creation of alternative transportation routes can therefore be considered antifragile strategies, as they reduce organizational vulnerability arising from geographical concentration. This finding is consistent with studies in antifragile supply chains and international trade, which highlight the importance of operational flexibility, supplier diversification, and dynamic contractual arrangements in reducing environmental risks. Moreover, the role of "operational and contractual flexibility" as a linkage factor indicates that antifragility in international trade environments requires simultaneous coordination among legal, logistical, and marketing structures. In the market and competition scenario, "product innovation" emerged as the most significant driving factor. This finding suggests that organizations operating in highly competitive markets cannot survive solely by relying on traditional products and fixed business models. Product innovation not only facilitates branding and the development of substitute products but also enables entry into new markets and the establishment of diverse contractual relationships. This finding is aligned with theories of dynamic competitive advantage and dynamic capabilities, which emphasize that successful organizations continuously reconfigure their products and business models. In addition, the findings are consistent with studies in innovation management and antifragility, which identify innovation as one of the most critical mechanisms for transforming crises into opportunities.

Across the three scenarios, the comparative analysis reveals that although the nature of the factors differs across domains, a consistent underlying pattern emerges. Strategic and flexible variables consistently act as driving forces, whereas operational and execution-oriented variables tend to be more dependent. In the economic scenario, flexible financial management played a foundational role; in the political–geographical scenario, export market diversification and flexible contracts emerged as key drivers; and in the market–competition scenario, product innovation was identified as the primary driving factor. This pattern indicates that managerial antifragility is formed when managers simultaneously develop financial, strategic, and innovative dimensions within the organization. Accordingly, antifragility is not a temporary characteristic but a systemic and dynamic capability that is strengthened through continuous learning, diversification, flexibility, and innovation. Overall, the findings suggest that companies aiming to effectively manage financial and business risks in turbulent environments should move beyond traditional and static approaches and instead adopt antifragile management models. Such an approach can enhance organizational competitiveness, reduce vulnerability, and enable the transformation of crises into opportunities for sustainable growth and development. The model evaluation results indicated that the proposed model demonstrates satisfactory validity and goodness of fit, as all factor loadings exceeded 0.2 and t-values were above 1.96, confirming the significance of relationships and supporting the acceptance of the research hypotheses. Furthermore, the RI value of 0.726 indicates that the antifragility model of commercial managers explains approximately 72% of the variance in corporate financial risk management. The fI and QI values also indicate strong effect size and adequate predictive relevance of the model. Overall, the findings demonstrate that managerial antifragility plays an effective role in improving financial risk management and enhancing firms' capacity to cope with crises and environmental volatility.

5.1. Comparison with Previous Studies

The findings of the present study are broadly consistent with previous research on organizational antifragility, while extending the existing literature by placing managerial antifragility at the center of corporate financial risk management. Khodaparast et al. (2023), in their study of antifragility in textile supply chains, emphasized the importance of identifying critical stressors and developing capabilities that enable organizations to adapt and improve under conditions of uncertainty and disruption. Consistent with this perspective, the present study demonstrates that managerial antifragility can translate exposure to financial and environmental uncertainty into opportunities for adaptive action through greater financial and operational flexibility. The findings also support the results of Corvello et al. (2024), who demonstrated that tangible slack resources, intangible resources, and absorptive capacity contribute to organizational antifragility and that antifragility is positively associated with financial performance in innovative start-ups. In line with these findings, the present study highlights financial flexibility, resource reconfiguration, and adaptive managerial responses as important mechanisms through which firms can respond constructively to financial shocks rather than merely absorb their negative effects. However, while Corvello et al. (2024) primarily examined the organizational resources underlying antifragility and its relationship with performance, the present study focuses specifically on the managerial dimension of antifragility and its implications for financial risk management. The findings are also consistent with Moradi and Seyghali (2025), who emphasized the role of antifragile business processes in enabling firms to transform disruption and volatility into opportunities for organizational learning and growth. The present study extends this process-oriented perspective by demonstrating that managerial antifragility can influence financial risk management through mechanisms such as financial flexibility, operational adaptability, market diversification, dynamic contractual arrangements, product innovation, branding, and the development of substitute products. These findings suggest that antifragility is not simply a characteristic of organizational processes or resources but can also be understood as a managerial capability that shapes how firms interpret, respond to, and strategically exploit uncertainty. Overall, the present study extends previous research in three important respects. First, it shifts the focus of antifragility research from predominantly supply-chain and organizational-level analyses toward the managerial level. Second, it establishes a direct conceptual and empirical link between managerial antifragility and corporate financial risk management, an area that remains relatively underexplored in the existing literature. Third, it demonstrates that effective financial risk management under uncertainty involves more than risk reduction or organizational recovery; it also requires the ability to reconfigure resources, diversify markets, maintain financial flexibility, and pursue innovation in response to adverse conditions. Accordingly, the findings reinforce the view of managerial antifragility as a strategic capability through which firms can not only withstand uncertainty but also learn, adapt, and create opportunities for improved performance and sustainable competitive advantage.

5.2. Practical Recommendations

Accordingly, the following recommendations are presented:

- **Institutionalizing an Antifragile Mindset among Managers and Organizational Leaders:** The findings of the study indicated that flexible financial management, innovation, and dynamic decision-making are among the most important determinants of managerial antifragility. Accordingly, organizations are advised not to rely solely on traditional managerial training programs, but to design specialized coaching programs aimed at developing an "antifragile mindset." In this approach, managers should learn that crises are not merely threats but can serve as platforms for business model reinvention, identification of new opportunities, and correction of inefficient structures. Managerial coaching can help reduce fear-based and conservative cognitive patterns, while strengthening managers' ability to analyze ambiguity, make decisions under uncertainty, and learn from failure. Such a mindset enables managers to avoid reactive and defensive responses during crises and instead guide organizations toward growth amid turbulence.
- **Designing Dynamic and Multi-Layered Financial Structures to Reduce Corporate Vulnerability:** The findings revealed that flexible financial management is the most influential factor in corporate financial risk management. Therefore, it is recommended that organizations move away from rigid financial structures toward agile financial models. This includes establishing intelligent liquidity reserves, diversifying revenue streams, reducing dependence on a single income source, and developing scenario-based financial planning for crisis conditions. From a coaching perspective, managers should develop "scenario thinking," enabling them to design multiple alternative pathways for organizational continuity before crises occur.

Such structures not only reduce the risk of financial distress but also enable firms to identify and exploit investment and growth opportunities faster than competitors during turbulent periods.

- **Developing an Organizational Culture Based on Learning from Failure and Continuous Feedback:** One of the main barriers to antifragility in organizations is fear of mistakes and a blame-oriented culture. The results showed that antifragile organizations transform crises and errors into opportunities for learning and improvement. Accordingly, managers should create an environment in which employees can openly share unsuccessful experiences without fear, allowing the organization to use these insights to improve processes. In a coaching-oriented approach, failure is not the end of the path but a valuable source of data for individual and organizational development. Conducting structured crisis review sessions, documenting unsuccessful experiences, and establishing continuous feedback loops can help organizations avoid repeating mistakes and instead use them as drivers of learning and innovation.
- **Strengthening Strategic Flexibility through Market Diversification and Dynamic Contracts:** The qualitative findings indicated that export market diversification and flexible contracts play a key driving role in reducing political and geographical risks. Accordingly, firms are advised to avoid excessive dependence on a single market, supplier, or customer and instead design multiple alternative pathways for sales, procurement, and logistics. From a coaching perspective, managers should develop “non-linear thinking,” enabling them to avoid linear forecasting based solely on current conditions and prepare for unexpected scenarios. Flexible contracting, collaboration with diverse partners, and the development of alternative markets help organizations avoid operational lock-in during crises and enhance adaptability.
- **Continuous Investment in Innovation and Development of Substitute Products:** The study found that product innovation is the most important driving factor in the market and competition scenario. This indicates that antifragile organizations do not remain passive in the face of market changes; rather, they actively become agents of change by creating new products and services. Therefore, it is recommended that managers allocate a portion of organizational resources to research and development, experimentation with new ideas, and continuous assessment of evolving customer needs. In a coaching framework, managers should foster a “creative and opportunity-oriented mindset” within teams so that employees are not merely process executors but active contributors to solution generation. This approach not only enhances competitive advantage but also strengthens organizational resilience and even increases robustness against market shocks.
- **Shifting Risk Management from Crisis Control to Opportunity Creation:** Many organizations view risk management solely as a tool for minimizing losses; however, the findings of this study indicate that antifragility emerges when organizations can

extract growth opportunities from crises. Accordingly, managers are encouraged to shift risk management from a defensive and reactive approach toward a learning-oriented and opportunity-driven perspective. For instance, during economic downturns, instead of cutting investments entirely, organizations can focus on areas where competitors are weakening. In a coaching-oriented approach, managers should recognize that every crisis contains valuable information about weaknesses, opportunities, and future market directions. Such a perspective can transform organizations from vulnerable entities into antifragile and growth-oriented systems.

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AI Governance as a Catalyst or Constraint of Creative Destruction in Digital Trade: Toward a Theory of Governed Digital Market Transformation

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Abstract

Artificial intelligence is revolutionizing digital markets by altering how businesses engage with customers, innovate, compete, add value, and engage in global trade. While a lot of research has been done on artificial intelligence as a source of automation, productivity growth, and innovative business models, less focus has been placed on the institutional factors that determine whether AI leads to productive creative destruction or strengthens market concentration and regulatory barriers. In order to explain how artificial intelligence governance can both facilitate and impede the transformation of digital markets, this conceptual paper develops the theory of governed creative destruction. The paper makes the case that the economic effects of artificial intelligence are based on the creative destruction tradition, research on technological innovation and competition, digital trade literature, platform economics, and new research on agentic e-commerce. The study also identifies agentic commerce as a significant new mechanism that could change the structure of digital markets by transferring consumer search, recommendation, comparison, and transaction decisions to autonomous or semi-autonomous agents. According to the resulting framework, effective artificial intelligence governance should maintain the conditions that allow for experimentation, entry, competition, innovation, and market reallocation in addition to lowering technological risks. In addition to developing theoretical ideas for further empirical research, the paper provides a conceptual framework for comprehending the transformation of digital trade as a controlled process of creative destruction.

Keywords: Agentic Commerce, Artificial Intelligence, Creative Destruction, E-Commerce

چکیده

این مقاله مفهومی پیشرو، با تمرکز بر اقتصاد دیجیتال و سازمان‌دهی صنعتی، پیوند میان هوش مصنوعی، ساختار بازار و سیاست‌گذاری را واکاوی می‌کند. پژوهش با عبور از نگاه تقلیل‌گرایانه به هوش مصنوعی صرفاً به‌عنوان ابزار اتوماسیون و ارتقای بهره‌وری، بر یک دوراهی نهادی بنیادین دست می‌گذارد: آیا هوش مصنوعی پیشران «تخریب خلاق مولد» خواهد بود یا به ابزاری برای «تمرکز بازار و انحصار پلتفرمی» تبدیل می‌شود؟ نوآوری نظری مقاله، تدوین چارچوب «تخریب خلاق هدایت‌شده» است که از پیوند سنت اقتصاد شومپیتری، اقتصاد پلتفرم، ادبیات تجارت دیجیتال و پدیده نوظهور «تجارت عاملیت‌محور» حاصل آمده است. تجارت عاملیت‌محور با واگذاری فرآیندهای جستجو، مقایسه و تراکنش مالی به ایجنت‌های خودمختار، قواعد رقابت سنتی در بازارهای دیجیتال و بین‌الملل را دگرگون می‌سازد. از دیدگاه اقتصاد صنعتی و سیاست‌گذاری بازرگانی، پیام مقاله شفاف است: حکمرانی هوش مصنوعی نباید صرفاً واکنشی، پدافندی و متمرکز بر کاهش ریسک‌های فنی باشد؛ بلکه باید سازوکارهای نهادیِ تسهیل ورود بنگاه‌های نوپا، آزمایش‌گری، رقابت منصفانه، کاهش موانع تعرفه‌ای-فناورانه و بازتخصیص پویای منابع را صیانت کند تا ساختار بازارهای جدید از بن‌بست انحصارگرایی در امان بماند.

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1. Introduction

A new stage in the growth of digital markets has been brought about by the quick spread of artificial intelligence. While modern artificial intelligence is increasingly altering how economic decisions are made and carried out, previous waves of digital transformation mainly altered how information was stored, communicated, distributed, and accessed. Demand forecasting, product recommendations, price optimization, marketing content creation, fraud detection, customer interaction automation, logistics coordination, financial decision support, and a host of other tasks that previously required direct human involvement can all be completed by artificial intelligence systems. Artificial intelligence is no longer just an information technology that businesses use to enhance current procedures as these capabilities are integrated into digital platforms and business infrastructures. It is increasingly being used as a tool for changing business models, market structures, and competitive relationships.

This transformation is particularly significant in digital trade and e-commerce because digital markets depend heavily on information, data, algorithms, platforms, and network effects. A firm operating in a digital market can reach consumers across geographical boundaries, coordinate transactions through platform infrastructures, personalize interactions at scale, and use data to continuously refine its products and services. Artificial intelligence intensifies these characteristics by reducing the cost of prediction, classification, personalization, search, and decision-making. Consequently, the competitive advantage of firms may increasingly depend not only on conventional resources such as capital and physical assets but also on access to data, computing capacity, algorithmic capabilities, digital infrastructure, and the institutional conditions under which these resources can be used.

The theory of creative destruction makes this development's economic significance more apparent. According to Aghion and Howitt's (1992) conceptualization, economic growth is a process whereby new innovations supplant established products and technologies, resulting in profits for successful innovators and losses for established firms whose technologies become outdated. Innovation is both creative and destructive, according to their framework. While the destructive dimension represents the displacement of current economic activities, the creative dimension results from the introduction of new goods, procedures, and technologies. Philippe Aghion and Peter Howitt were specifically honored with the 2025 Sveriges Riksbank Prize in Economic Sciences for their theory of sustained growth through creative destruction. This theory emphasizes that technological advancement can lead to conflicts that need to be handled constructively in order to prevent established interests from impeding innovation.

Artificial intelligence provides a particularly important contemporary setting for examining this process. Unlike many earlier technologies that primarily replaced specific physical or routine tasks, artificial intelligence can influence activities involving prediction, communication, information processing, creativity, decision support, and increasingly complex coordination. This creates the possibility that creative destruction will occur at several levels simultaneously. At the firm level, artificial intelligence can displace established business processes. At the industry level, it can alter the boundaries between producers, intermediaries, platforms, and service providers. At the market level, it can change how consumers discover products, compare alternatives, and make purchasing decisions. At the institutional level, it can challenge existing regulatory categories and require new approaches to competition, consumer protection, data governance, and digital trade.

However, socially beneficial creative destruction is not always the result of technological capability. Artificial intelligence's economic effects are contingent upon the institutional context of technological innovation. A regulatory framework may impose costs that disproportionately affect smaller businesses, but it may also foster confidence and predictability that encourage businesses to invest in cutting-edge technologies. Dominant platforms may not be able to suppress new competitors by controlling data, computing infrastructure, or digital interfaces thanks to competition policy, but poorly crafted regulations may also hinder lawful experimentation. While excessively restrictive or fragmented data regimes may decrease interoperability and hinder cross-border digital trade, data protection may boost consumer trust and strengthen the legitimacy of digital services. Governance therefore occupies an ambiguous position: it can function as a catalyst for creative destruction or as a constraint on it.

This paper's main theoretical issue is represented by this ambiguity. Artificial intelligence has been studied from the viewpoints of productivity, automation, labor markets, innovation, competition, ethics, and regulation in the past. The internationalization of digital services, data-driven business models, and digital platforms have all been the subject of other studies. However, these literatures are frequently created independently. While artificial intelligence governance literature primarily concentrates on risk management, accountability, transparency, safety, and ethical principles, creative destruction literature explains why technological innovation transforms markets. Cross-border data flows, market access, digital infrastructure, and regulatory fragmentation are all highlighted in research on digital trade. The growing body of research on agentic commerce explores the potential for artificial intelligence agents to change consumer behavior when making purchases online. Relationship theory is still lacking.

Thus, the idea of controlled creative destruction is developed in this essay. The main contention is that artificial intelligence-driven creative destruction should be viewed as an institutionally mediated process in which governance establishes the parameters under which innovation can enter, compete, scale, displace incumbents, and create new markets rather than as an unregulated technological process. The process by which AI-driven innovations change or replace established technologies, companies, services, and business models within institutional frameworks intended to manage technological risks while maintaining innovation, competition, consumer trust, market entry, and digital trade is known as "governed creative destruction.".

The idea is purposefully more expansive than responsible artificial intelligence. In general, responsible AI places a strong emphasis on preventing harm and ensuring that AI systems adhere to moral, legal, and social norms. By examining whether governance maintains the institutional and competitive conditions necessary for innovation-driven transformation, governed creative destruction adds an economic and market-structural component. According to this viewpoint, disruption cannot be completely eradicated by a successful governance system. Instead, it is one that minimizes technological advancements that lead to systemic harm, exclusion, manipulation, or anticompetitive concentration while permitting constructive disruption.

The main contributions of the paper are four. By viewing governance as a factor that determines the course and degree of technological market transformation, it first combines creative destruction theory with artificial intelligence governance and research on digital trade. Second, it lists a number of institutional mechanisms, such as regulatory certainty, competition policy, data governance, consumer trust, regulatory interoperability, and support for experimentation, through which governance may impact creative destruction. Third, rather than focusing only on product or process innovation, it develops agentic commerce as a crucial new setting where creative destruction may function at the level of market architecture. Fourth, it puts forth a number of theoretical claims that can direct upcoming empirical studies on the connection between digital market transformation and AI governance.

This argument is developed through an integrative conceptual analysis in the rest of the paper. By tying together technological innovation, digital platforms, artificial intelligence, and creative destruction, the following section lays the theoretical groundwork. The following sections look at how governance affects e-commerce and digital trade, why agentic commerce might be a new phase of market transformation, and how these developments lend credence to the governed creative destruction theory. Future research directions are identified and theoretical, managerial, and policy implications are discussed in the paper's conclusion.

2. Theoretical Background and Literature Foundations

2.1 Creative Destruction and Innovation-Driven Growth

The idea of "creative destruction" is linked to Schumpeter's (1942) explanation of capitalism as an evolutionary process whereby new products, markets, organizational structures, and technologies constantly supplant more established ones. The key realization is that economic growth cannot be reduced to the accumulation of resources already in place. Rather, structural change is how development arises. Incumbents are challenged by new businesses, old production techniques are rendered obsolete by new technology, and new organizational structures change the dynamics of competition. Therefore, the reallocation of resources across activities is essential to economic advancement.

By creating a model of growth via creative destruction, Aghion and Howitt (1992) formalized this intuition. According to their theory, innovation boosts output while also making current technologies outdated. Because successful innovators can earn financial gains while incumbents risk losing their market share, the process creates incentives for innovation. This framework was expanded by later studies that looked at productivity growth, competition, innovation incentives, and the connection between firm-level technological change and overall economic performance (Aghion et al., 2001. Aghion et al., 2005. Aghion et al., 2015).

The current study is especially pertinent to the significance of institutions in this process. Because technological change produces winners and losers, creative destruction leads to distributional conflicts. Governments may be under political pressure to defend established industries, workers may oppose technologies that threaten their jobs, and incumbent businesses may oppose new competitors. Aghion and Howitt's 2025 Nobel Prize acknowledgment made it clear that the conflicts brought about by creative destruction must be handled positively since established businesses and interest groups could otherwise stifle innovation.

This insight provides an important starting point for understanding artificial intelligence governance. If creative destruction necessarily generates conflict, then institutions determine, at least partly, whether that conflict results in productive adaptation or technological stagnation. Governance is therefore not external to innovation. It forms part of the environment through which innovation is selected, adopted, diffused, and translated into economic transformation.

The creative destruction framework also suggests that technological progress should not be evaluated only by the performance of individual technologies. A new technology may be highly productive while producing limited aggregate innovation if market structures prevent entry or if incumbent firms use their existing advantages to appropriate the benefits. Conversely, a technology with modest standalone productivity effects may generate substantial economic transformation if it enables new firms, business models, and markets to emerge. This distinction becomes especially important for artificial intelligence because AI capabilities can be embedded across multiple layers of the digital economy.

2.2 Artificial Intelligence as a General-Purpose Transformation Mechanism

In contrast to many traditional digital technologies, artificial intelligence is capable of carrying out or enhancing a wide range of cognitive and information-intensive tasks. Automation research has demonstrated that technologies can complement some tasks and replace others, resulting in complex effects on demand, employment, productivity, and organizational design (Autor et al. (2003; 2019, 2020; Acemoglu and Restrepo). According to more recent research, artificial intelligence's economic effects cannot be solely attributed to technological substitution because it can also generate new tasks, increase product variety, enhance prediction, and boost demand (Bessen, 2019; Brynjolfsson et al. in 2021).

A key component of creative destruction is the distinction between augmentation and substitution. Artificial intelligence may mainly have operational effects if it merely automates an already-existing process. Its effects become structural if it allows businesses to rethink how value is produced, distributed, and captured. An e-commerce company might first use AI to predict inventory demand, for instance. AI may then be used to manage customer service, optimize delivery routes, automate marketing campaigns, personalize product recommendations, and manage pricing. At a later stage, the company might completely rethink the customer journey around AI-mediated shopping and discovery. A deeper level of organizational transformation is represented by each stage.

Artificial intelligence's versatility also means that as it spreads, complementary innovations may result. Cockburn and associates. (2018) contend that because advances in machine prediction can change the cost structure of tasks that previously relied on human judgment, AI may have widespread innovation effects. Complementary investments in data, software, organizational procedures, human resources, and digital infrastructure could result from such changes. Similar to this, Brynjolfsson, Rock, and Syverson (2021) stress that complementary innovations are frequently needed for general-purpose technologies before their full productivity effects become apparent.

These complementarities present risks as well as opportunities from the standpoint of creative destruction. Businesses may adopt AI more quickly and scale its benefits more successfully if they have access to capital, data, talent, computing infrastructure, and established customer networks. These benefits can also result in cumulative concentration. The same technology that fosters innovation may increase incumbent market power if dominant firms control vital inputs into AI development and implementation. Access to high-quality data and processing power, as well as connections between various generative AI value chain stages, have been identified by the OECD as potential competition issues.

2.3 Digital Platforms, Data, and Market Power

Because competition often takes place within ecosystems rather than isolated markets, digital platforms produce a unique environment for creative destruction. Platforms connect various user groups, create network effects, gather data, and set technical guidelines for involvement. While subsequent platform research has shown how data, scale, and ecosystem control can reinforce competitive advantages, Shapiro and Varian (1998) highlighted the economic significance of information goods and network effects.

Because they can serve as a competitive advantage, a source of consumer insight, a mechanism of market control, and an input for innovation, data are especially significant. Goldfarb and Tucker (2019) demonstrate how digital technologies can alter information and marketing economics by lowering measurement and targeting costs. Data governance also establishes who has the authority to gather, process, transfer, combine, and profit from information. In addition to posing issues with privacy, governance, inequality, and cross-border regulation, data flows have become essential to economic growth and digital trade, according to the World Bank (2021) and UNCTAD (2021).

Because AI systems are able to convert vast amounts of data into predictions, recommendations, classifications, and decisions, artificial intelligence raises the strategic significance of data. As a result, data control can affect a company's ability to create new products as well as the caliber of its current offerings. This establishes a possible feedback loop: businesses with big user bases produce more data, better data may enhance AI performance, better AI may draw in more users, and more users produce more data. Incumbent advantages may be strengthened by such dynamics in the absence of competitive safeguards.

Data concentration is not intrinsically anticompetitive, despite this. Certain scale economies could lead to real efficiency gains. Therefore, the theoretical challenge is to differentiate between exclusionary and productive concentration. Incentives for businesses to invest in data and AI must be maintained by AI governance and competition policy, but control over vital digital resources cannot be used as a tool to stifle innovation and entry.

3. AI Governance as an Institutional Determinant of Digital Market Transformation

The field of artificial intelligence governance has grown to include organizational, legal, ethical, technical, and regulatory mechanisms for managing AI systems. Principles like accountability, transparency, safety, human oversight, privacy, justice, and respect for human rights are becoming more and more important in international frameworks. For instance, the OECD AI Principles emphasize human rights, democratic values, transparency, robustness, security, and accountability while encouraging creative and reliable AI. In order to take into account advancements such as generative and general-purpose AI, the principles were revised in 2024 after being adopted in 2019.

However, governance should be examined from the standpoint of creative destruction not just in terms of lowering risk but also in terms of how it affects market dynamics. The anticipated costs and advantages of innovation are influenced by a governance framework. It has an impact on businesses' understanding of the requirements they must meet, their ability to test new products, consumer confidence in AI-enabled services, competitors' access to vital inputs, and the cross-border operation of digital services.

Thus, one of the key mechanisms connecting governance and innovation is regulatory certainty. When businesses are able to predict regulatory expectations, they are more inclined to invest. Because businesses might not know if an AI application will eventually be banned, subject to expensive compliance requirements, or restricted in specific jurisdictions, uncertainty can cause investment delays. Thus, long-term investment and experimentation can be promoted by regulatory clarity. This does not imply that more innovation results from less regulation. Instead, the predictability and proportionality of governance are the pertinent variables.

A second mechanism concerns consumer trust. Digital markets depend on consumers being willing to share information, use digital payment systems, rely on recommendations, and interact with automated services. If consumers perceive AI systems as manipulative, unsafe, opaque, or discriminatory, adoption may decline. Governance can therefore support innovation indirectly by establishing standards that increase confidence. Privacy protection, explainability where appropriate, mechanisms for contesting automated decisions, and accountability for harmful outcomes can contribute to market legitimacy.

Competition is the third mechanism. When dominant firms are prevented from using AI capabilities to exclude competitors, AI governance may become a catalyst for creative destruction. Issues like discriminatory access to platform interfaces, preferential treatment of a platform's own services, limitations on data portability, exclusive control over computing resources, and algorithmic coordination that stifles competition can all be addressed by competition-oriented governance. The OECD's analysis of competition, data, and AI shows why these concerns are becoming more and more important as AI value chains grow.

However, if compliance costs are disproportionately high for smaller businesses, governance may limit creative destruction. Legal departments, technical compliance teams, cybersecurity resources, and financial capacity are common features of large firms that allow them to absorb regulatory requirements. Startups and smaller businesses might have to pay more in comparison. Therefore, if a regulation has a high fixed cost of compliance, it may have asymmetric competitive effects. A central paradox results from this. By limiting powerful companies, governance can safeguard competition while also decreasing it if compliance requirements keep smaller businesses from entering the market. Therefore, the impact of governance on creative destruction is not always positive or negative, but rather contingent.

Proposition 1: The relationship between artificial intelligence governance and creative destruction is contingent on the balance between risk reduction, regulatory predictability, compliance costs, and competitive openness.

This proposition distinguishes the present framework from approaches that treat governance as inherently supportive or restrictive. Governance should instead be conceptualized as an institutional technology whose economic effect depends on how its rules interact with market structure.

4. Digital Trade and E-Commerce Transformation

One of the most significant settings where AI-driven creative destruction can take place is digital trade. Digital technologies allow businesses to reach customers without having a physical presence in every market, facilitate cross-border communication, lower information and transaction costs, and enable remote service delivery. By enabling small and medium-sized businesses to reach global clients via digital channels, the expansion of e-commerce has consequently altered the geography of trade. These effects can be amplified by artificial intelligence. Predictive analytics can enhance inventory management and logistics, translation systems can lessen language barriers, recommendation systems can assist businesses in understanding foreign consumer preferences, and automated customer service can lower the cost of international operations. Fintech services and digital payments can also benefit from AI-driven risk assessment and fraud detection. AI can optimize routing and ware in smart logistics.

The significance of these applications extends beyond operational efficiency. They can change the minimum efficient scale required to participate in international markets. A small firm that previously lacked the resources to conduct multilingual marketing, maintain international customer support, or optimize cross-border inventory may increasingly use AI-enabled services to perform these functions at relatively low marginal cost. In this sense, AI can reduce some barriers to digital trade and expand market access.

However, the distribution of these benefits is not automatic. Differences in digital infrastructure, skills, access to finance, data availability, and regulatory capacity can produce unequal outcomes. Firms and countries with advanced digital ecosystems may adopt AI more rapidly, while firms in less developed environments may face barriers to computing infrastructure, talent, and reliable connectivity. The result may be a form of digital creative destruction in which some firms gain access to new markets while others are displaced without possessing the capabilities required for adaptation.

Another level of complexity is added by regulatory fragmentation. While regulatory requirements are still geographically dispersed, digital services often transcend national boundaries. For businesses operating globally, different regulations pertaining to data protection, AI risk classification, consumer rights, cybersecurity, digital taxation, and platform responsibilities can raise transaction costs. As a result, regulatory interoperability may play a significant role in the competitiveness of digital trade.

From this perspective, governance should not be understood exclusively as national regulation. The cross-border nature of digital commerce requires coordination among jurisdictions. International principles, interoperable standards, mutual recognition mechanisms, and compatible approaches to data governance can reduce unnecessary regulatory barriers while preserving legitimate policy objectives.

Proposition 2: Regulatory interoperability strengthens AI-driven creative destruction in digital trade by reducing cross-border compliance friction and enabling innovative firms to scale across jurisdictions.

The idea does not suggest that regulatory diversity should be eliminated by harmonization. Different standards that reflect social preferences and legal traditions may be legitimately adopted by different jurisdictions. Theoretically, companies' capacity to scale innovation globally may be hampered by excessive incompatibility.

For creative businesses, a digital market with interoperable regulations can offer a more expansive and efficient market. Data governance is also crucial. Data processing and movement are becoming more and more important to cross-border digital commerce. Businesses use transaction data to identify fraud, forecast demand, customize services, and improve logistics. Data movement restrictions may occasionally be justified for reasons related to security, privacy, or public policy. However, fragmented data regimes can also make it more challenging for businesses to create cross-border AI applications and lower the effectiveness of digital services. Thus, it is not the proper goal of governance.

Proposition 3: Responsible data governance supports creative destruction when it protects legitimate privacy and security interests while preserving sufficient data access, portability, and interoperability for innovation and competition.

The significance of consumer behavior is further demonstrated by e-commerce. Customers who shop online traditionally must search, compare products, assess information, and decide what to buy. These tasks are increasingly automated by artificial intelligence. While generative systems can summarize reviews, compare products, and offer tailored buying advice, recommendation systems already have an impact on consumer choice. The consumer may transition from being an active searcher to a decision-delegator as these systems become more independent.

This shift modifies the competitive landscape while also opening up new business opportunities. Visibility may be determined by the preferences and algorithms of the AI intermediary rather than by conventional search-engine ranking, advertising, brand recognition, or physical location if customers stop visiting multiple websites and instead rely on the intermediary to choose products. Thus, “How does a firm become selected by the consumer’s AI agent?” becomes the competitive question instead of “How does a firm attract consumers?”.

5. Agentic Commerce and the Transformation of Market Architecture

One of the most important new trends in AI-enabled e-commerce is agentic commerce. The consumer continues to be the main decision-maker in traditional e-commerce, conducting product searches, comparing options, reading reviews, and completing transactions. An AI agent may carry out some or all of these tasks on behalf of the customer in agentic commerce. A natural-language request can be interpreted by the agent, who can also find pertinent products, compare features and prices, evaluate reviews, offer suggestions, and possibly finish the transaction.

Because it advances artificial intelligence from the level of interface personalization to the level of market coordination, this shift is significant. The AI system can act as an intermediary through which a consumer experiences a market, rather than just assisting them in navigating it. Demand creation, product discovery, seller visibility, advertising, pricing, and platform competition can all be impacted by such a change.

AI agents may behave differently from human shoppers, according to preliminary research. Allouah et al. (2025) investigate AI agents in simulated e-commerce settings and report on the possibility of demand concentration around a small number of products, heterogeneous model behavior, position effects, and varying sensitivity to price, ratings, and reviews. Additionally, their results imply that market share may be impacted by seller-side optimization aimed at AI preferences. Although these results are preliminary, they point to a significant theoretical possibility: the competitive mechanism by which products gain market attention may change as AI-mediated demand emerges.

Businesses make significant investments in social media, brand development, advertising, website design, search engine optimization, and customer relations in human-centered commerce. If AI agents base their purchasing decisions mostly on structured product information, price, ratings, compatibility, dependability, and inferred consumer preferences, then some of these activities may become less significant in agentic commerce. Instead, companies can optimize machine-readable attributes, reputation signals, data feeds, APIs, and product descriptions for AI consumption. This could lower some entry barriers. If an AI agent determines that the product is a better fit, a small company with a better product may be able to reach customers without making significant investments in brand awareness. By enhancing the capacity of creative entrants to compete with well-established brands, such a mechanism could reinforce creative destruction.

On the other hand, the opposite result is just as likely. A few AI middlemen may become strong gatekeepers if they control the majority of product discovery. Which companies receive demand may be determined by their ranking systems, recommendation models, commercial incentives, or access regulations. As a result, market dominance may shift from traditional merchants and search engines to AI middlemen. A new kind of platform dependence is produced by this possibility. Sellers in conventional digital marketplaces optimize for both platform algorithms and human consumers. Sellers may need to optimize for AI agents that function within platform ecosystems in agentic markets. As a result, the competitive landscape may become recursive: businesses tailor their products to AI systems, AI systems make decisions for customers, customers affect seller behavior, and sellers try to influence AI recommendations. There are important governance ramifications for this recursive structure. if AI agents consistently give preference.

Proposition 4: The transition from human-mediated e-commerce to agentic commerce increases the importance of AI governance because AI systems increasingly participate in consumer choice, product discovery, and transaction execution.

Making agents accurate is only one aspect of the governance challenge. If the agent is consistently biased toward specific sellers, platforms, or commercial incentives, accuracy is insufficient. Therefore, governance needs to take the AI intermediary's market role into account. Agentic commerce's growth raises additional concerns regarding consumer autonomy. Customers may benefit from efficiency and convenience if they assign decisions to AI agents, but they may also lose awareness of the factors influencing their purchases. This puts autonomy and personalization at risk of conflict.

The more decisions are delegated, the more crucial it is that consumers comprehend the limits of delegation and maintain channels for contestation and intervention. Thus, agentic commerce can be viewed as a potential innovation in market architecture from the standpoint of creative destruction. Previous digital changes altered the way buyers and sellers communicated. Agentic commerce.

6. Toward a Theory of Governed Creative Destruction

The previous analysis suggests that the interaction between technology, markets, and institutions should be the basis for AI-driven creative destruction. Governance shapes the environment in which these processes occur, firms translate capabilities into products and business models, consumers respond to new offerings, and technology creates new capabilities. The resulting transformation is not regulated or technologically predetermined.

Five interconnected ideas form the basis of the theory of governed creative destruction developed here. First, market disruption is possible with technological innovation, but its economic outcome is not determined. Furthermore, the presence of institutions has an impact on the ability of innovative companies to enter, experiment, scale, and compete. Third, governance can create new barriers to innovation while simultaneously reducing harmful externalities. Furthermore, the significance of data, platforms, and interoperability is enhanced by digital markets. Fifth, governance is becoming more and more concerned with the architecture of markets as AI becomes directly involved in consumer decision-making, not just firms and technologies.

Innovation openness is the first dimension. In order to create creative destruction, it is essential to have chances to challenge established arrangements by introducing fresh concepts. Even when regulatory systems effectively minimize individual risks, they can still lead to a decrease in innovation due to the excessive cost of experimentation. By allowing regulators to observe emerging risks, regulatory sandboxes, proportionate requirements, phased compliance, and clear guidance can support experimentation.

Competitive neutrality is the second dimension. While AI-driven markets have the potential to generate substantial economies of scale, it is crucial for new entrants to have a compelling chance to challenge incumbents in order to achieve competitive advantage. Therefore, in order to maintain competitive neutrality, consumer attention, digital interfaces, data access, and distribution channels must be given priority. The governance of these resources should prevent dominant firms from transforming control into exclusionary barriers.

Trusted participation is the third dimension. Trust is essential for digital markets. Consumers need to possess a belief in the security, fairness, and reliability of digital services, while firms need to possess a belief in the stability and enforceability of rules. Therefore, regulatory interoperability is the fourth dimension, and governance can increase the size and quality of digital markets when it strengthens trust.

The advantages of AI innovation are primarily attributed to the ability of companies to expand across jurisdictions due to the cross-border nature of digital trade. The fifth dimension of adaptive governance is the ability of interoperable standards to minimize unnecessary friction while enabling governments to uphold legitimate policy objectives. Static regulation becomes challenging due to the rapid evolution of AI technologies. Therefore, as business models, market structures, and technological capabilities change, governance frameworks must be capable of updating rules. Because AI agents' behavior can change as models are updated, deployed in new contexts, or integrated with external tools, adaptive governance is especially important for agentic commerce.

These dimensions suggest that the number of risks addressed or laws passed should not be the sole criteria used to assess the quality of governance. Whether governance fosters an atmosphere where socially beneficial innovation can flourish while detrimental forms of concentration, manipulation, exclusion, and systemic risk are restrained is a more significant criterion. Therefore, governed creative destruction is defined by the theory as: The institutionally mediated process through which AI-driven innovations create, transform, and displace technologies, firms, services, and business models under governance arrangements that manage technological risks while preserving innovation, competition, consumer trust, market entry, and digital trade.

There is one significant difference between this definition and traditional creative destruction. The economic mechanism that innovation uses to displace incumbents is the main focus of classical creative destruction. The institution is specifically incorporated into governed creative destruction.

Proposition 5: Regulatory certainty positively influences AI-driven creative destruction when it reduces uncertainty without imposing disproportionate fixed compliance costs on innovative entrants.

This proposition highlights the distinction between regulation and regulatory uncertainty. A clear regulatory framework can be more innovation-friendly than a weak but unpredictable framework. Firms need to understand the rules of the market in which they invest. Predictability reduces the option value of waiting and can encourage firms to commit resources to experimentation and commercialization.

Proposition 6: The positive effect of AI governance on creative destruction decreases when compliance costs disproportionately burden startups and small and medium-sized enterprises relative to incumbent firms.

The proposition follows from the fixed-cost structure of digital innovation. Many regulatory requirements involve investments in legal expertise, documentation, cybersecurity, testing, monitoring, and organizational processes. Large firms can spread these costs across large revenues and product portfolios. Smaller firms cannot. Governance that ignores this asymmetry may unintentionally protect incumbents.

Proposition 7: Competition-oriented AI governance strengthens creative destruction when it prevents incumbent firms from using control over data, digital infrastructure, platform interfaces, or AI-mediated distribution to restrict market entry.

This proposition connects AI governance with the classical conflict between innovation and incumbent protection. If incumbents can use their market position to prevent technological challengers from reaching customers, the creative destruction mechanism weakens. The problem is not that incumbents are successful but that success becomes a mechanism for preventing future competition.

Proposition 8: Consumer trust mediates the relationship between responsible AI governance and adoption of AI-enabled digital commerce.

Trust is particularly important where consumers delegate decisions to AI. Consumers may tolerate limited uncertainty in conventional search because they retain direct control over purchasing decisions. Delegation increases the perceived consequences of errors or manipulation. Governance that establishes accountability and transparency can therefore support adoption.

Proposition 9: Regulatory fragmentation weakens AI-driven creative destruction in cross-border digital trade by increasing compliance costs and reducing the scalability of innovative digital services.

This proposition extends the analysis beyond domestic competition. A firm may develop an innovative AI-enabled service but remain unable to scale internationally if each market requires substantially different compliance structures. Fragmentation therefore acts as a friction on the diffusion of innovation.

Proposition 10: AI-driven creative destruction becomes more structurally disruptive when artificial intelligence moves from process automation toward business-model and market-architecture transformation.

This proposition distinguishes incremental adoption from transformative adoption. Automating customer service may reduce costs, while redesigning commerce around autonomous purchasing agents can change the structure of demand itself. The latter represents deeper creative destruction because it changes the roles of consumers, platforms, intermediaries, and sellers.

Proposition 11: The emergence of agentic commerce increases the potential for market-power redistribution from traditional platforms and sellers toward AI intermediaries that control consumer decision interfaces.

This proposition identifies an important possible shift in digital market power. If the primary interface between consumers and sellers becomes an AI agent, control over that interface may become economically more valuable than conventional storefront or search visibility.

Proposition 12: Inclusive AI-driven creative destruction depends on complementary institutional capabilities, including digital infrastructure, human capital, access to finance, data capabilities, and regulatory capacity.

The proposition recognizes that technological disruption can create unequal outcomes. Firms cannot benefit from AI simply because the technology exists. They require complementary resources. Consequently, governance should be evaluated partly according to whether it expands the capacity of diverse firms and regions to participate in technological transformation.

7. Theoretical Contributions and Discussion

The literature benefits from the theory of governed creative destruction in a number of ways. It first applies the theory of creative destruction to digital and AI-mediated markets. The emphasis of classical creative destruction is on replacing current technologies with novel ones. By stating that governance affects the circumstances in which replacement takes place, the current framework incorporates institutional mediation. Because technologies function within infrastructures that are frequently regulated, platform-mediated, and heavily dependent on data, this is especially pertinent in digital markets.

Second, by offering a market-dynamics viewpoint, the framework advances research on AI governance. Fairness, accountability, safety, transparency, and privacy are among the concepts that are frequently discussed in AI governance literature. These ideas are crucial, but how they interact with innovation and competition will determine how they affect the economy. Unintentionally, a regulation can safeguard consumers.

Third, by highlighting regulatory interoperability as a mechanism for innovation, the framework advances research on digital trade. The ability of businesses to conduct business internationally is critical to digital trade. The effective market accessible to innovative companies may be significantly smaller than the technological market appears to be if regulatory systems are highly fragmented. Therefore, by increasing the number of markets in which digital innovation can be implemented, interoperability can raise its economic value.

Fourth, the theory offers a conceptual link between emerging agentic commerce and platform economics. Conventional platform research concentrates on the middlemen that link buyers and sellers. An AI system that can act on behalf of customers and possibly negotiate or transact is a new kind of intermediary introduced by agentic commerce. Because the intermediary can actively interpret preferences and make decisions instead of just providing a mark, this alters the nature of intermediation.

Machine-mediated attention is another new competitive item brought about by the rise of agentic commerce. Businesses compete for people's attention in traditional digital commerce. Businesses may compete more fiercely for algorithmic selection in agentic commerce. This could alter platform relationships, pricing, reputation management, product design, and marketing tactics. Businesses may optimize for both the AI systems that represent consumers and for consumers themselves.

The potential for a new type of digital market concentration is increased by this development. Sellers might become reliant on their selection processes if a small number of AI agents take over as decision interfaces. As a result, platform concentration may give way to intermediary concentration in the competitive dynamics. However, if AI agents make it simpler for customers to recognize better products regardless of brand size, agentic commerce may lessen some types of concentration.

The outcome will depend on governance. Transparent recommendation criteria, consumer control, auditing, portability, interoperability, and competition policy may prevent AI intermediaries from becoming opaque gatekeepers. Conversely, exclusive arrangements, preferential ranking, hidden commercial incentives, and restrictions on interoperability could transform AI agents into new mechanisms of market foreclosure.

This tension illustrates why governed creative destruction is a useful theoretical construct. Creative destruction is not inherently beneficial or harmful. It describes a process of transformation. The welfare consequences depend on what is destroyed, what is created, who can participate, and how the transition is governed.

The theory also provides a more nuanced interpretation of regulatory intervention. Rather than asking whether governments should regulate artificial intelligence, researchers and policymakers should ask what forms of governance preserve the conditions for productive market transformation. This shifts the policy question from "regulation versus innovation" to "what type of governance makes innovation more competitive, trustworthy, and inclusive?"

8. Managerial and Policy Implications

For managers, the theory implies that AI strategy should not be separated from governance strategy. Firms increasingly need to treat regulation, data governance, cybersecurity, consumer trust, and competition conditions as components of their innovation environment. An organization that develops technically sophisticated AI capabilities but fails to anticipate regulatory or trust-related constraints may be unable to commercialize those capabilities effectively.

Digital firms should also recognize that AI adoption can generate second-order competitive effects. An AI system introduced to reduce costs may change customer expectations, alter competitor behavior, and create new market standards. Firms should therefore evaluate AI investments not only according to immediate productivity gains but also according to their potential to reshape industry structure.

In e-commerce, firms should prepare for the possibility that consumers increasingly interact with AI agents rather than directly with websites and applications. This may require investment in machine-readable product information, structured data, reliable APIs, transparent pricing, accurate inventory information, and product attributes that can be evaluated algorithmically. Marketing strategies may also need to evolve from optimizing only for human attention toward ensuring that products are discoverable and appropriately represented in AI-mediated environments.

For policymakers, the theory suggests that AI regulation should incorporate competition and innovation objectives alongside safety and consumer protection. Regulatory frameworks should avoid unnecessarily high fixed costs for startups while maintaining strong requirements for high-risk applications. Regulatory sandboxes and staged compliance mechanisms may be particularly useful where technologies are rapidly evolving.

Competition authorities should also monitor the relationship between AI systems and platform power. Relevant questions include whether dominant platforms control essential data or computing resources, whether AI systems discriminate against competing services, whether platform-owned AI systems receive preferential access or ranking, and whether recommendation systems create systematic barriers to entry.

Consumer protection authorities will increasingly need to consider AI-mediated purchasing. If consumers delegate decisions to AI agents, they should have meaningful control over preferences, budgets, commercial permissions, and transaction limits. They should also be able to understand when commercial relationships influence recommendations and have mechanisms to contest harmful or erroneous decisions.

Digital trade policy should prioritize interoperability. International cooperation can reduce regulatory friction without requiring every jurisdiction to adopt identical rules. Compatible approaches to data governance, AI standards, digital identity, cybersecurity, and consumer protection can facilitate cross-border commerce while preserving legitimate regulatory autonomy.

Developing economies require particular attention. If AI-driven creative destruction depends on complementary infrastructure, skills, finance, and data capabilities, countries lacking these resources may experience displacement without obtaining equivalent benefits. International digital trade policy should therefore include capacity-building mechanisms that allow smaller firms and less digitally advanced economies to participate in AI-enabled markets.

9. Conclusion

A new stage of the digital market transformation is being ushered in by artificial intelligence, where technological innovation is increasingly influencing not only production processes but also business models, consumer behavior, market intermediation, and the architecture of digital trade. Because it explains why innovation simultaneously creates new economic opportunities and destroys established technologies and competitive positions, the theory of creative destruction offers a potent foundation for comprehending this transformation. However, since governance has a significant impact on the course of technological change, this framework needs to be expanded for the digital and AI context.

To close that gap, this paper developed the idea of governed creative destruction. Within institutional settings that aim to manage technological risks while maintaining innovation, competition, consumer trust, market entry, and digital trade, AI-driven innovations transform and displace current technologies, businesses, services, and business models. This process is known as “governed creative destruction.”. The main contention is that the effectiveness of governance should not be the only criterion used to assess it. It should also be assessed based on whether it maintains the economic mechanisms that allow productive innovation to challenge established arrangements.

The analysis demonstrates that AI governance can function as both catalyst and constraint. Regulatory certainty, consumer trust, competition safeguards, responsible data mobility, regulatory interoperability, and support for experimentation can strengthen creative destruction by reducing uncertainty and widening opportunities for entry and innovation. In contrast, fragmented regulation, disproportionate compliance costs, restrictive data regimes, and weak competition safeguards can suppress innovation or reinforce incumbent advantages.

The emergence of agentic commerce makes this issue increasingly urgent. When AI systems begin to search, compare, recommend, and transact on behalf of consumers, they can become new intermediaries in digital markets. This may reduce search costs and create opportunities for innovative firms, but it may also shift market power toward AI systems and platforms that control consumer decision interfaces. Early empirical work already suggests that AI agents can display systematic and model-dependent shopping behaviors, including position effects, varying sensitivities to product attributes, and potential concentration of demand.

The more general implication is that businesses shouldn’t view the next phase of digital transformation as a straightforward competition to implement AI. It is a process of reorganizing the market and institutions. Artificial intelligence is already causing disruption, so the main question is not whether it will. The more crucial question is whether institutions can manage that disruption to maintain open innovation, meaningful competition, consumer protection, and widespread access to the benefits of digital trade.

The ideas presented in this paper should be empirically tested in various nations, sectors of the economy, and regulatory frameworks in subsequent studies. Comparative research could investigate whether higher rates of AI startup entry and innovation are linked to regulatory certainty. Studies at the firm level could look into whether compliance burdens have different effects on small and large businesses. The question of whether regulatory interoperability boosts the global scaling of AI-enabled services could be investigated in research on digital trade. Lastly, studies on agentic commerce ought to look into how market concentration, consumer welfare, advertising, product discovery, and seller strategies are impacted by AI-mediated purchasing.

Therefore, the main theoretical claim of this paper is simple: AI-driven creative destruction is neither institutionally neutral nor technologically predetermined. The governance framework in which technological innovation enters and changes digital markets determines its distribution, intensity, and direction. As a result, effective AI governance should be created to regulate not just artificial intelligence but also the circumstances that allow AI to create inclusive, competitive, productive, and trustworthy market transformation.

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