CONTEMPORARY PERSPECTIVES ON INNOVATION MODELS: FROM TECHNOLOGY PUSH TO THE QUADRUPLE HELIX

Stefan Ghimisi, Prof.dr.eng, ***Constantin Brâncuși University of Targu Jiu***

ABSTRACT. Innovation remains a central driver of economic growth and societal transformation in the twenty-first century. Over the decades, innovation models have evolved from linear, technology-driven frameworks toward complex, interactive, and collaborative systems involving multiple stakeholders. This paper reviews the evolution of innovation models—from the early Technology Push and Market Pull paradigms to more contemporary frameworks such as the Chain-Link, Triple Helix, and Quadruple Helix models [1, 2]. It highlights how digital transformation, artificial intelligence, and sustainability imperatives are reshaping innovation ecosystems. The study concludes that the future of innovation depends on systemic collaboration between academia, industry, government, and civil society, supported by data-driven and sustainable policies.

Keywords:Innovation, Technology Push, Market Pull, Triple Helix, Quadruple Helix, Open Innovation, Digital Transformation, Sustainability

1. Introduction

Innovation has become the cornerstone of economic competitiveness and societal advancement in the digital age. Global challenges such as climate change, digitalization, and demographic shifts require new approaches to creating and diffusing knowledge. Historically, innovation was perceived as a linear process driven by technological discovery or market demand. However, contemporary innovation models emphasize interactive learning, feedback mechanisms, and multi-stakeholder collaboration. This paper explores the conceptual evolution of innovation models, assessing their relevance in the context of global transformation.

2. Evolution of Innovation Models

In 1941, English economist Schumpeter formulated the initial concept of innovation in the technical-economic domain, noted for its broad applicability. He contends that innovation is the process that leads to the formation of any entity or an alternative output. Schumpeter [3,4] defines innovation as encompassing the introduction of a new product, the adoption of novel manufacturing techniques, the penetration of a new market, the use of new materials, the reorganization of the enterprise, and the establishment of a new corporate identity.

A multitude of inventions emerges from the quest for novel opportunities. An aspiring innovator must comprehend the fundamentals of invention. These notions can be refined to promote creativity.

Therefore:

1. Sustain a proactive mindset; innovators relentlessly seek new ideas, opportunities, and avenues for innovation.
2. To present the innovation of products, processes, or services in a clear and understandable manner. Individuals must easily understand the principles of innovation.
3. To achieve products, processes, and services that correspond with client preferences.
4. To commence minor-scale innovation.
5. The imperative for certain lofty objectives. Successful inventors ought to seek a niche market for their distinctive products. Innovators must follow the principle: experiment, assess,

contemplate. Extract insights from mistakes. Innovation does not guarantee success. Analyzing errors may foster greater inventiveness.
6. It is essential to establish a schedule for the innovative project that include routine evaluations.
7. Individuals substantially involved in innovation endeavors deserve suitable acknowledgment and compensation.

The earliest models of innovation were linear, portraying innovation as a sequence of stages from research to market application. The "Technology Push" model emphasized the primacy of scientific research and technological development as the starting point for innovation. This method includes product design and development that may be carried out with few resources and at a competitive cost. Thus, the market is regarded as a beneficiary of the products generated by the research and development process. An increase in research and development leads to enhanced innovation. Historically, governments in numerous nations have promoted innovation by offering direct financial support for research and development. A research and development team proposes adequate comprehension of client needs to independently build a new product without consumer participation.

The technology push strategy to innovation has not always succeeded, as proposed innovations are sometimes insufficiently appreciated by customers, leading to goods that do not fulfill expectations.

In contrast, the "Market Pull" model focused on responding to consumer needs and market demands as the main source of innovation. In this model, innovation begins **in the marketplace**—from observed or expressed customer problems—and drives the research and development (R&D) process toward solutions that satisfy those needs.

In contrast, the "market pull" paradigm asserts that the driving force behind innovation stems from customers or specific market sectors. These needs may be discerned by entrepreneurs, producers, or consumers as clearly apparent. This model asserts that successful innovation necessitates an initial analysis of market demands, defining the requirements of existing products and processes, and determining how to fulfill the needs of new innovative products.

The Market Pull Model involves going through the following stages:

1.Market Need Identification

- Companies observe consumer behavior, analyze market trends, or receive direct feedback.
- The key question: *"What do customers want or need?"*

2. **Idea Generation**
   - Ideas are developed to meet the specific demand.
   - Can come from marketing teams, sales staff, or customer suggestions.
3. **Research & Development (R&D)**
   - Technical teams design or improve products to meet the identified demand.
   - Focus is on applying existing technology rather than inventing new ones.
4. **Prototype Development and Testing**
   - Early models or concepts are tested with consumers for feedback.
   - Adjustments are made to ensure product-market fit.
5. **Production**
   - Once validated, the innovation enters mass production.
6. **Marketing and Commercialization**
   - Marketing emphasizes how the product fulfills specific customer needs.
   - Distribution and promotion strategies follow.

The method has the following advantages

- High chance of market success (since innovations are demand-driven).
- Better customer satisfaction and brand loyalty.
- Efficient resource use—efforts focused on known market gaps.
- Encourages close alignment between marketing and R&D departments.

But also the disadvantages

- Can **limit creativity**—companies focus only on expressed needs, not unspoken or future ones.
- May **miss radical innovations** that create entirely new markets.
- Competitors can easily imitate demand-driven innovations.

While both models contributed to early industrial and technological progress, their linear logic proved insufficient to capture the complex dynamics of modern innovation systems that involve feedback loops, learning, and cross-sectoral interaction.

Figure 1.Technology Push Model

Figure 2. Market Pull Model

3. The Chain-Link and Open Innovation Paradigms

This represents a third-generation model of innovation proposed by SJ Kline and N. Rosenberg (1986) [5]. It introduced the idea that innovation arises through multiple feedback loops between research, design, production, and market interaction. This iterative process reflects real-world practices where knowledge creation and application are intertwined. Building on this foundation, Chesbrough (2003) [6] introduced the concept of 'Open Innovation', emphasizing that firms must leverage both internal and external sources of knowledge to innovate effectively. In the current digital economy, open innovation practices are further enhanced by digital platforms, data analytics, and collaborative technologies that enable cross-sectoral co-creation.

This model features five relationships within the innovation process, outlining the diverse sources of invention and information relevant to innovation. The principal link to the index marked by arrow C (Central Chain) enables a process generalization that emerges in reaction to market demands, innovation, or analytical design, development, and manufacture, culminating in the marketing process.

The second phase of the innovation process incorporates feedback from the duration of the first phase. The paramount component of feedback, denoted as F, originates from the consumer or user who will become the future customer of the innovation. This relationship underscores that innovation is propelled by client demands, or that it entails consumer-centric innovation processes. The second link depicts the feedback obtained within the organization, referred to as f (feedback), and delineates the company's initiatives to tackle or evade challenges that may arise at different stages of innovation, or

the origin of innovation, which is based on experiential learning (learning by doing).

The tertiary connection in the fundamental relationship between the innovation process and knowledge. The relationship between innovation and fundamental research is denoted by D (discoveries); for example, many innovations are intricately linked to the scientific research process, as illustrated by partnerships between corporations and universities.

The fourth factor in the innovation process, denoted by K (knowledge), indicates that the principal source of innovation is existing knowledge, succeeded by newly emerging knowledge when the current knowledge is inadequate to meet demands.

The fifth connection, labeled I (Innovation), represents the prospects for scientific advancement afforded by innovation. This denotes the utilization of innovations to perform scientific research that will produce new technologies.

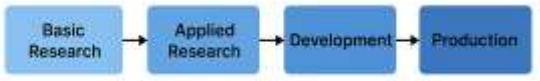

Figure 3 Chain-Link Model

4. The Triple and Quadruple Helix Models

The Triple Helix model, introduced by Etzkowitz and Leydesdorff (2000) [7], conceptualizes innovation as a dynamic interaction between three institutional spheres: universities, industry, and government. Universities generate knowledge and foster entrepreneurship; industry transforms knowledge into economic value; and government provides regulatory and financial frameworks that support innovation. This model has been instrumental in shaping national and regional innovation systems.
The Triple Helix Model conceptualizes innovation as a **non-linear, interactive process** among three institutional spheres:

1. **Universities (Academia)** – act as centers of knowledge creation, research, and human capital development. Beyond traditional roles, universities increasingly engage in entrepreneurship through technology transfer and spin-off companies.
2. **Industry (Private Sector)** – represents the application of knowledge to generate economic value through products, services, and market-oriented innovation. Industry participation ensures the practical relevance and commercialization of research outcomes.
3. **Government (Public Sector)** – provides the regulatory, financial, and infrastructural environment necessary for innovation. Governments set priorities through policy, incentives, and investments that support research and entrepreneurial initiatives.

The **intersection of these three spheres** constitutes the "innovation space," a hybrid domain where collaboration and co-creation occur.

The "triple helix" of university-industry-government relationships is a contemporary evolutionary framework for evaluating the knowledge-driven innovation process in the economy. Henry Etzkowitz (2002) characterizes the "triple helix" as a spiral innovation model that clarifies the interconnections at different phases of the knowledge accumulation process. This concept has been analyzed by various Romanian academics, including Miron, D. (2008) [8].

The paradigm incorporates the three "institutional spheres": research, industry, and government. The initial group consists of researchers engaged in the implementation of innovative concepts, designs, and technologies they generate, alongside institutions that establish educational programs centered on new

occupational skills for prospective graduates.

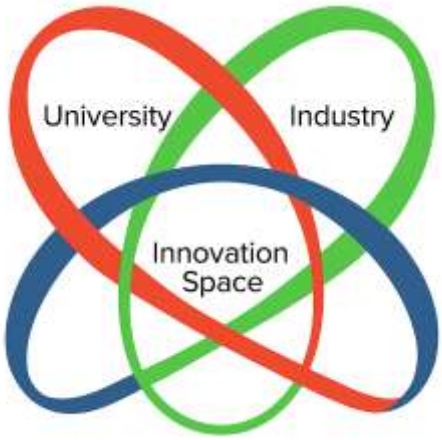

Figure 4. The Triple and Quadruple Helix Models

The second category comprises decisional elements within the sector, including entrepreneurs, investors, managers, and executives. The third group encompasses decisional variables within the legislative and executive branches of the state, which legally govern the operational circumstances of industry, research centers, universities, and the allocation of public funds for research and development and education.

Advantages of the Triple Helix Model

The model provides several key benefits:

- **Synergy creation**: Integrates scientific research, market mechanisms, and public policy.
- **Efficient resource allocation**: Enhances the effectiveness of investments in R&D.
- **Knowledge transfer**: Facilitates the translation of research results into practical innovations.
- **Economic growth**: Strengthens national competitiveness and supports the emergence of knowledge-based industries.

The triple helix model comprises three primary forms. In the "triple helix I" concept, three spheres—university, industry, and government—are institutionally delineated. Interactions occurring across boundary spheres are facilitated by institutions such as industry liaison offices, technology transfer centers, and contract offices.

In "Triple II Helix," the helix is characterized as distinct communication systems, comprising market operations, technology innovation, and control over interfaces. The "Helix Triple III" concept posits that institutional spheres—university, industry, and government—interchange their functions, with institutions adopting a quasi-governmental function as facilitators of regional or local innovation.

The triple helix model has faced criticism for its abstract nature.

5. Practical Applications in the European and Romanian Context

At the European level, programs such as Horizon Europe and the European Innovation Council foster innovation ecosystems that reflect the Quadruple Helix approach. These initiatives encourage cross-sectoral cooperation and support projects that integrate technological, social, and environmental dimensions. The European Union's Smart Specialisation Strategies [9] promote regional innovation policies aligned with local strengths and knowledge bases. The Digital Europe Programme and the European Green Deal further emphasize the need for sustainable and inclusive innovation that contributes to digital transformation and climate neutrality.

In Romania [10] the innovation landscape has gradually evolved through partnerships between universities, industry, and government agencies. Programs such as PNCDI IV and RO-Horizon, coordinated by UEFISCDI, illustrate efforts to integrate research and business sectors. Science and technology parks in Bucharest, Iași, and Timișoara, as well as regional innovation clusters such as Cluj IT Cluster, reflect the growing importance of Triple Helix

collaboration. Local initiatives like Cluj Innovation City and various smart city projects demonstrate how innovation can drive economic development and societal modernization when supported by coherent public policies.

6. Discussion: Toward Collaborative and Digital Innovation Ecosystems

The ongoing digital transformation has fundamentally reshaped innovation ecosystems. Artificial intelligence, big data, and automation have expanded the scope and speed of knowledge creation. At the same time, sustainability challenges demand responsible innovation practices that balance economic growth with environmental and social goals. The convergence of technological and societal forces calls for a systemic, inclusive, and adaptive approach to innovation governance.

Future innovation systems must be characterized by openness, interdisciplinarity, and co-creation across sectors and regions. Policymakers should design mechanisms that foster trust, reduce institutional barriers, and enable agile collaboration between stakeholders.

7. Conclusion

Innovation is no longer confined to laboratories or corporate R&D departments; it is a collective and iterative process shaped by diverse actors. The evolution from Technology Push to the Quadruple Helix model illustrates the growing complexity of innovation systems in a knowledge-based economy. Sustainable progress depends on continuous interaction among universities, industry, government, and society. As digitalization accelerates and global challenges intensify, embracing collaborative and open innovation frameworks will be essential for building resilient, inclusive, and sustainable economies.

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