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Innovation Diffusion Factors in the Digital Transformation Era: Integrating Innovations in Technology, Economy, Society, and Policy

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Abstract This study examines the factors driving the diffusion of technological innovation across economic, societal, and policy domains. Using a systematic literature review and qualitative content analysis, it develops an analytic framework grounded in an integrated innovation model that extends existing innovation theories. It identifies three sources of influence—environment, technology, and conversion—that are crucial to the diffusion of innovation. Findings suggest that successful innovation diffusion requires coordinated interactions among technology, economy, society, and policy, highlighting the role of governmental intervention and policy innovation. The study contributes to understanding the co-evolution of innovation across multiple social domains and offers practical insights for integrative innovation policies in the digital transformation era. Future research should quantitatively validate and refine the identified diffusion factors.

Keywords innovation diffusion; integrated innovation model; co-evolution of innovation; digital transformation; systematic literature review

I. Introduction

Technological innovation remains central to addressing societal challenges, from economic instability to public health crises. Historically, early discussions sparked by Schumpeter (1934) predominantly emphasized corporate interests as the main engine of innovation. However, the contemporary landscape, shaped

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significantly by digital transformation (DX), demands a broader perspective that considers interactions among economic, social, and policy dimensions. Recent advances in information and communication technologies (ICT), artificial intelligence (AI), big data, and robotics exemplify how technological developments simultaneously transform industries, labor markets, and societal structures, posing both opportunities and complex new problems. As Geels (2004) observed, the impetus for innovation now extends beyond economics to include broader social demands.

Earlier innovation studies largely adopted linear and micro-level perspectives. From their perspective, the diffusion of technology is often viewed as a one-dimensional process that focuses on either features or user perceptions of technology, under the assumption that research and development (R&D) automatically leads to commercialization. Nevertheless, in today's era of DX, recent studies (e.g., Yi et al., 2018; Yi et al., 2019; Lee and Yi, 2021; Yoo and Yi, 2022) have begun to acknowledge the dynamic interplay between technology and society, underscoring how technological changes trigger significant social shifts, creating demands for subsequent technological adaptation. This fundamental shift illustrates a broadening of focus from micro-level processes to a macro perspective, recognizing the reciprocal influence of technology and society on innovation.

In this respect, the current study revisits major innovation theories from a macro-level perspective to explore factors influencing innovation diffusion across economic, social, and policy domains. By integrating these findings, this research provides a comprehensive framework that emphasizes the interconnectedness inherent in innovation processes.

In doing so, the current study contributes to both innovation theory and policy. First, it expands the integrated innovation model by examining interactions among the technology, economic, social, and policy domains. By identifying the factors that drive innovation diffusion, this study provides insights into how technological innovation spreads across various domains of society. Second, it provides policymakers with actionable insights by identifying specific drivers of innovation diffusion, informing the development of integrative policy measures. Policymakers may pinpoint specific policy needs from a more integrated perspective and devise novel policy options that are more comprehensive than existing innovation strategies.

The manuscript is structured as follows: Sections 2 and 3 explore the theoretical foundations and contextual changes that drive innovation. Section 4 presents the analytical framework and its operationalization, followed by Section 5, which outlines the research methodology and identifies key factors of innovation diffusion. Section 6 synthesizes findings, highlighting implications for innovation theory and policy. The study concludes with a discussion of its limitations and recommendations for future research.

II. Theoretical Backgrounds

1. Early Innovation Theories and the Evolution of Innovation Theories

Early innovation scholarship laid the groundwork for technological determinism, focusing on the transformative impact of innovative technology and its role in propelling social change. Attracted by the ability of technology to reshape society, these early studies primarily focused on how technological progress drives social transformation (White, 1962; Heilbroner, 1967). Innovation research influenced by this perspective has continued to build upon Schumpeter's earlier discussion (e.g., neo-Schumpeterian and endogenous growth theories), emphasizing that technology underpins economic growth and promotes further innovation through the application of scientific and technological knowledge.

Nevertheless, the Social Construction of Technology (SCOT) perspective, which views technology as a social construct shaped by human choices, stresses that factors beyond technology—ranging from political and economic conditions to cultural and institutional norms—simultaneously determine the trajectory of social changes along with technology (Sawyer and Hilton, 1963). Departing from technological determinism, it highlights the diverse actors in multiple domains who introduce and adopt new technologies that transform society (Williams and Edge, 1996).

Building on the SCOT's perspective, more recent approaches have sought to understand the highly contextual, complex, and dynamic nature of the technology-society relationship. For example, evolutionary economics (Witt, 1993) emphasizes that economies are dynamic systems evolving through innovation and adaptation, driven by interactions among various social actors. Similarly, the innovation systems perspective (Freeman, 1987; Lundvall, 1988) underscores the importance of networks—among enterprises, universities, research institutes, financial institutions, and government agencies—in sustaining and spreading innovation. Finally, the socio-technical systems approach (Grin et al., 2010) integrates both technological and social dimensions, emphasizing that the interplay between technology and society is inseparable and that innovation must consider social values such as sustainability and inclusiveness.

2. Integrated Innovation Model

Building on these evolving perspectives, the integrated innovation model posits that the domains of technology, economy, society, and policy are

inseparably interrelated at a macro level (Meissner, Polt, and Vonortas, 2017; Yi et al., 2018; Yi et al., 2019; Lee and Yi, 2021; Lee et al., 2022; Yoo and Yi, 2022). While existing theories often overlook how emerging technologies reshape the economic, social, and policy domains—and the conditions required for such technology to yield significant impacts across society—the integrated innovation model emphasizes this broader transformative capacity.

Studies (e.g., Meissner et al., 2017; Yi et al., 2018; Yi et al., 2019; Lee and Yi, 2021; Lee et al., 2022; Yoo and Yi, 2022) proposing the integrated innovation model suggest that innovation is never an isolated phenomenon; rather, it permeates four interconnected domains—technology, economy, society, and policy—and drives transformative changes throughout the social system. The model further underscores the importance of policy innovation, both in content and process, as a means of fostering social innovation. Policy innovation aligns with perceptual and institutional transitions rooted in economic innovation—the shifts in the economy and its structure that emerge when technological innovation leads to the production and application of new scientific knowledge.

3. Broadening the Scope: Diffusion of Innovation

The integrated innovation model recognizes that a single technological breakthrough can have a 'butterfly effect,' radically transforming society as innovations diffuse at an unprecedented pace. Once perceived as a mere tool or means, technologies are now increasingly regarded as a form of knowledge—defined as information, understanding, and skills gained through education or experience (Oxford University Press, 2021). In the context of innovation, knowledge underpins decision-making and actions that drive innovative processes. Thus, technology, as a form of knowledge, not only facilitates innovation diffusion but also channels social demands for innovation (Fey and Birkinshaw, 2005; Leiponen and Helfat, 2010; Jeong et al., 2015).

Three streams of innovation literature examine how knowledge informs the innovation process. The first explores how tacit and explicit knowledge is disseminated through social networks, thereby diffusing innovation (Nonaka and Takeuchi, 1995; Chen et al., 2016; Nonaka, 1994). The second emphasizes specialized scientific and technological knowledge—generated by research institutes and universities—as essential for enhancing innovation capabilities (Pérez-Luño et al., 2019; Hartono and Sheng, 2016; Sheng et al., 2015). Third, business administration research underlines knowledge management's role in fostering organizations' innovative potential (du Plessis, 2007; Adams and Lamont, 2003; Darroch and McNaughton, 2002; Pyka, 2002; Hartono and Sheng, 2016). These streams underscore that knowledge is central to initiating, sustaining, and expanding the diffusion of innovation across multiple social domains.

Furthermore, recent studies propose ‘knowledge push’ as an innovation driver, complementing the previously recognized ‘technology push’ and ‘demand pull’ (Tidd and Bessant, 2018). In the DX era, knowledge’s role has evolved beyond physical tools, becoming integral to innovation processes. Additionally, urgent social challenges (e.g., climate change) underscore the need for innovative technological knowledge, highlighting the growing importance of technological knowledge in innovation. This reflects that innovation today emerges not only from tangible technologies or market requirements but also from the production, dissemination, and application of new knowledge.

From the perspective of the integrated innovation model, innovation can be understood as the diverse endeavors of public and private actors to resolve social issues, fulfill intellectual curiosity or enhance utility by generating, utilizing, linking, and disseminating scientific and technological knowledge (Lee and Yi, 2021). In this context, technology is conceptualized as more than a mere tool; it is a form of knowledge that functions as infrastructure, encompassing a broad range of changes in technological capabilities, work processes, lifestyles, and value systems. As such, technology drives social transformation not only by enhancing economic efficiency and growth, but also by reshaping social relationships and altering individual ways of life and value systems.

Examples include ICT, AI, the Internet of Things (IoT), cloud computing, big data, mobile technologies, and cybersecurity. ICT provides essential infrastructure for both work and daily activities, while AI and IoT enable cyber-physical systems, prompting policy discussions on issues like robot taxation and universal basic income. Thus, knowledge applied in production generates demand for new systems, rules, and norms, shifting societal paradigms. As technological knowledge diffuses and becomes universal, it intensifies interconnections across technology, economy, society, and policy, addressing pressing social and global challenges (Hazelkorn and Gibson, 2019). significantly expanding the scope and impact of innovation.

III. Contextual Background: Digital Transformation (DX)

Before examining the diffusion factors of innovation, this section provides an overview of broader contextual changes in the innovation environment and technology driven by recent digital transformation (DX).

1. Increasing Connectivity in Social Systems and Diverse Innovation Stakeholders

DX significantly reshapes innovation environments by promoting extensive societal changes through digitization and the adoption of ICT. Emerging technologies profoundly alter economic and social interactions, creating new business models, transforming job markets, and prompting shifts in labor regulations (Ebert et al., 2018; Lee and Yi, 2021). At the same time, innovation—once led by individual firms—has now evolved into a network-based collaborative process. While private firms remain key actors, innovation increasingly unfolds through interactions among diverse stakeholders — research institutes, private firms, and government agencies—within broader networks and platforms where diffusion occurs. Consequently, a holistic view that encompasses the global dimensions of these innovation networks becomes essential (Eun, 2021).

2. Changing Nature of the Market: From Competition to Collaboration

Traditionally, innovation research (e.g., Kraft, 1989; Vossen, 1999; Geroski, 1990; Jorde and Teece, 1990; Zhang and Islam, 2021) often emphasized competitive market dynamics as drivers of innovation. However, recent research (e.g., Becker and Dietz, 2004; Szucs, 2018) suggests that cooperation is often more conducive to innovation. Multi-directional interactions among firms, government agencies, universities, and research institutes now characterize innovation, highlighting strategic networking and collaboration as essential for successful diffusion (Amoroso, 2017; Evangelista, 2000; Kline and Rosenberg, 2009; Malecki, 1997).

3. Digital Technology as Ubiquitous Infrastructure

Digital technology functioning as ubiquitous infrastructure now underpins a wide range of innovations (Bresnahan and Trajtenberg, 1995). As a general-purpose technology (GPT), digital technologies serve as a foundational enabler across industries by reducing costs of use over time and fostering continual innovation (Lee et al., 2011). ICT exemplifies a digital GPT as an infrastructure that boosts industrial productivity, creates new business opportunities, and benefits consumers, functioning like roads or electricity by supporting various services.

4. Convergence and Integration of Scientific and Technological Knowledge

ICT has blurred traditional sectoral boundaries, triggering technological convergence and generating new industries. Advances in convergent technologies (e.g., big data, IoT, AI with cognitive abilities, augmented/mixed reality (AR/XR), autonomous vehicles, and cloud computing) further intensify interactions among industries, sparking new products, services, or even entirely new business sectors (Yi et al., 2018). Examples include smart factories enabled by AI and robotics, as well as smart cities arising from integrated ICT-driven urban management, which cause substantial shifts in both economic and social domains.

IV. Analytical Framework and Operationalization

Recognizing the need for a comprehensive understanding of innovation diffusion as a phenomenon that occurs within the entire social system, this study adopts a systematic approach to develop an analytical framework grounded in the integrated innovation model. A systematic approach can analyze complex social phenomena by considering the properties and structure of the system in question (Boulding, 1956). Accounting for individual components and their interactions, it understands a system composed of various interrelated elements from a macro perspective. From this standpoint, innovation diffusion can be conceptualized as an interconnected process involving inputs (innovative technology), conversion processes (actors adopting technology), and outputs (societal transformations). Figure 1 illustrates this process from a systematic perspective.

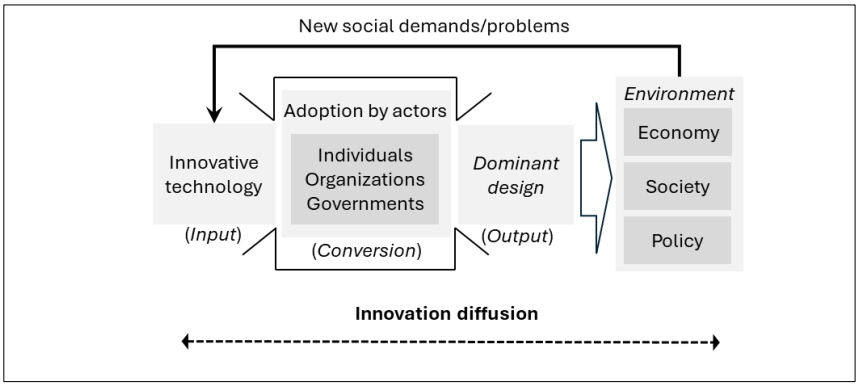

Figure 1. Analytic Framework

In this framework, the 'input' of the system is innovative technology. The characteristics of innovative technology affect how various actors adopt new

technology during the process. Previous studies (Rogers, 2003; Ram, 1987; Davis, 1989; Adams et al., 1992; Bhattacherjee, 2001; Zhou, 2008) have suggested that attributes such as usefulness and usability are important. Consequently, in the 'conversion' process, actors accept, adopt, and practically apply new technology. While previous studies have often focused on technology adoption at the individual level, the role of private corporations and governments is also critical in shaping the pace and scale of innovation diffusion. With their interests, competencies, and policy measures, these key actors lead the diffusion process across society. As the 'output' of the system, new technology achieves a dominant design, becoming widely adopted across various social domains and altering the existing socio-economic order. Based on new technological knowledge, new scientific and technological knowledge is generated, and various actors adopt it to change the economy, society, and policy, creating an ongoing cycle in which innovation both responds to and generates new social demands. This interplay fuels further changes in the economy, society, and policy domains, and all are channeled back into demands for further innovations and the diffusion of such innovations.

Furthermore, the current study adopts a broader concept of innovation that integrates both the 'innovation' process of creating something new and the 'diffusion' process through which this novelty spreads to other domains, building on the integrated innovation model. Thus, in this study, innovation diffusion is operationalized as a process in which innovative technology is adopted and introduced by various actors, becoming widely utilized across different domains of the economy, society, and policy, and ultimately transforming the entire society. This transformation, in turn, creates new demands that spur further innovations and subsequent diffusion cycles. From the operationalized definition based on the proposed analytic framework, three key sources of influence shaping the diffusion process are identified: the 'environment' impacted by innovation generating new demands for innovation, 'innovative technology' as an input of an innovation diffusion cycle, and the 'conversion' process led by actors adopting and applying innovative technology.

By identifying the three key sources of influence—the environment, innovative technology, and conversion—this study further categorizes the factors that shape the innovation process around these sources. Specifically, Environment Factor (F1) refers to environmental attributes, such as changes in the economic, social, and policy domains, that shape the innovation process. Technology Factor (F2) encompasses the characteristics of the new technology being diffused, such as ease of use and usefulness. Conversion Factor (F3) pertains to the attributes of actors (e.g., individuals, private firms, and governments) who adopt, introduce, and utilize the new technology during the conversion process. In this study's analysis, these three categories are used to classify the specific drivers of innovation diffusion identified. Based on the

study's analytic framework, these three factors are organized as illustrated in Figure 2.

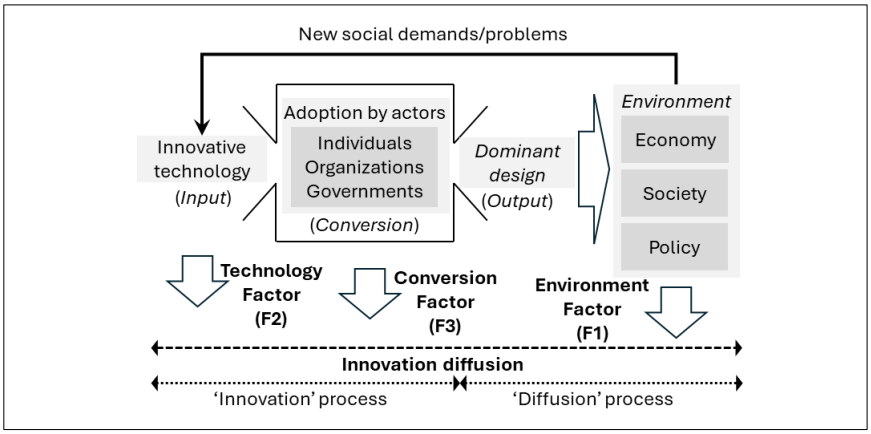

Figure 2. Key Diffusion Factors: Environment, Technology, and Conversion

V. Research Method and Analysis of Diffusion Factors

1. Research Method

This section outlines the literature review process and content analysis employed to examine previous studies on innovation diffusion. A systematic literature review is conducted to identify factors in earlier research that enable technological innovation to diffuse across economic and social domains. This approach minimizes selection bias and ensures a rigorous evaluation and synthesis of the relevant literature. Additionally, a narrative synthesis is employed based on the literature review, coupled with qualitative content analysis to integrate findings across heterogeneous study designs and contexts. A statistical meta-analysis is not pursued because constructs, operationalizations, and outcomes vary substantially across the included studies and fields, violating common-effect assumptions and rendering quantitative aggregation misleading for our macro-level purpose. Instead, to build an integrative framework spanning technology, economy, society, and policy, the current study prioritizes consistent selection logic and coding over statistical effect size. Nevertheless, this study further delineates testable propositions for future empirical research.

To establish clear criteria for inclusion and exclusion, the review focuses on macro-level discussions of the use of technology in economic and social contexts. Studies focusing solely on technology commercialization by a single

firm are excluded because they typically adopt a micro-level perspective centered on individual corporate innovation activities.

Research articles were drawn from leading journals in social science, business, economics, and management—fields closely related to innovation. The search process covered studies published up to 2021, and search terms including 'innovation diffusion,' 'innovation adoption,' and 'technology innovation diffusion' yielded 1,139 potentially relevant studies. These studies were then filtered based on additional keywords (e.g., 'diffusion factors,' 'adoption factors') in their abstracts and main texts. Studies that did not address technological innovation were excluded from the analysis. Google Scholar was used to confirm that no key studies were omitted. After reviewing the analyses and findings, articles that did not directly examine diffusion factors were excluded, resulting in a final sample of 67 studies. A qualitative content analysis was then conducted on these 67 studies using descriptive coding—that is, assigning concise codes (e.g., words or short phrases) to topics within the data.

2. Factors of Innovation Diffusion

Again, as this study adopts a broader definition of innovation compared to existing studies, innovation is understood both as the creation of new scientific and technological knowledge and as the diffusion process by which its outcomes are introduced and utilized across other social domains (Lee and Yi, 2021). In this context, innovation studies have approached the topic from two perspectives, each with a different emphasis on the innovation process. On the one hand, studies focus on narrowly defined innovation (i.e., the creation of new technology) and on how such technology is diffused. These studies identify the factors that influence individuals or organizations to adopt and utilize new technology. The other studies focus on the diffusion of innovative outcomes to investigate the conditions under which innovative outcomes spill over into other domains beyond technology within a social system. The former 'innovation' research includes research based on the Diffusion of Innovation Theory (DIT), the Technology Acceptance Model (TAM), the Integrated Model (IM) of Innovation, the Model of Innovation Resistance (MIR), and the latter 'diffusion' research includes studies using frameworks such as National Innovation System (NIS) and the Technology Innovation System (TIS).

2.1 Diffusion Factors from 'Innovation' Studies

To understand the factors driving the diffusion of innovative technology across economic, social, and policy domains, this study first reviews the factors identified in innovation studies. First, DIT focuses on socio-psychological factors contributing to the diffusion process by emphasizing communication characteristics (Tornatzky and Klein, 1982; Rogers, 2003). Rogers (2003)

suggests that the adoption of innovation is influenced by socio-psychological aspects such as 'perceived attributes of innovation,' 'type of innovation decisions,' 'communication channels,' 'nature of the social system,' and 'efforts of change agents.' Among these, he further argues that 'perceived attributes of innovation' determine the rate and scope of adoption, underscoring the importance of how individuals perceive new technology during its adoption and utilization. Specifically, it identifies five attributes that contribute to diffusion: 'relative advantage,' 'compatibility,' 'complexity,' 'trialability,' and 'observability.' Relative advantage refers to whether the innovation is more beneficial than existing alternatives; compatibility concerns whether the innovation is sufficiently valuable to replace current practices; complexity pertains to the effort required to understand or use the technology; trialability indicates whether the technology can be tested on a limited basis; and observability describes the extent to which the innovation is visible among potential adopters. These factors are classified as the Technology Factor (F2).

Second, TAM proposes diffusion factors by focusing on how information technology (IT) is accepted and utilized by users as new IT, such as computers, the internet, and other digital devices, become widespread. This model posits that individuals' perceptions of technology attributes—namely, 'perceived usefulness' and 'perceived ease of use'—influence their attitudes toward, and intentions to accept and use, new technology (Davis, 1989; Davis et al., 1989; Adams et al., 1992). These two factors can be classified as Technology Factor (F2) as they concern how new technology's perceived characteristics lead to its adoption.

Third, the Integrated Model (IM) of innovation incorporates existing innovation theories, including DIT, TAM, and the Expectation Confirmation Model, to provide a more comprehensive list of factors influencing innovation diffusion (Bhattacherjee, 2001; Zhou, 2008). Rather than focusing on a single technology, the IM examines factors that affect the adoption and utilization of innovative technology in broader contexts, such as information services (e.g., email or Internet services). Studies based on the IM have identified usefulness, ease of use, observability, continuous intention to use, user satisfaction, and social image as key factors. These factors relate to the attributes of new technology and the actors adopting it. Thus, they are classified as Technology Factor (F2) and Conversion Factor (F3).

Lastly, contrary to most diffusion studies that focus on factors promoting the adoption of innovation, the Model of Innovation Resistance (MIR) examines the factors that cause resistance to new technology. Studies employing MIR (e.g., Ram, 1987; Ram and Sheth, 1989; MacVaugh and Schinavone, 2010) investigating what deters the adoption of innovation argue that resistance stems from perceived risks and uncertainties. Thus, managing these resistance factors can also influence the diffusion of innovation. Specific resistance factors include

perceived innovation characteristics (i.e., relative advantage, compatibility, complexity, perceived risk, trialability, and observability), consumer characteristics (i.e., demographic and psychological variables), and propagation mechanisms (i.e., types and nature of communication channels) (Ram, 1987). Perceived innovation characteristics are classified as Technology Factor (F2), while both consumer characteristics and propagation mechanisms are classified as Conversion Factor (F3).

The factors identified by these studies, which focus on the narrow innovation process, are summarized in Table 1 below. As shown, existing studies have primarily addressed the Technology Factor (F2) and the Conversion Factor (F3), recognizing the significance of both the attributes of new technology and the actors who play central roles in diffusion, yet often overlooking the Environment Factor (F1) at the macro level.

Table 1. Diffusion Factors Presented in 'Innovation' Studies

Theory/Model	Source	Diffusion Factors	Classification
Diffusion of Innovation Theory (DIT)	Tornatzky and Klein (1982) Rogers (2003)	- Compatibility - Relative advantage - Compatibility - Relative advantage - Complexity - Trialability - Observability	Technology (F2)
Technology Acceptance Model (TAM)	Davis (1989) Adams et al. (1992)	- Perceived usefulness - Perceived ease of use	Technology (F2)
Integrated Model (IM) of Innovation	Bhattacherjee (2001) Zhou (2008)	- Usefulness - Ease of use - Observability	Technology (F2)
		- Continuous intention to use - User satisfaction - Social image	Conversion (F3)
Model of Innovation Resistance (MIR)	Ram (1987)	- Perceived innovation characteristics	Technology (F2)
		- Consumer characteristics - Propagation mechanisms	Conversion (F3)

2.2 Diffusion Factors from 'Diffusion' Studies

In contrast, diffusion studies examine the conditions under which innovative outcomes diffuse across broader social domains such as the economy, society, and policy. These studies, utilizing frameworks such as the National Innovation System (NIS) and the Technology Innovation System (TIS), examine the factors that enable innovation outcomes to extend beyond the technological domain.

First, these studies highlight the influence of market and social systems on corporate innovation. In particular, the degree of market competition (e.g., monopoly versus competitive market) and the extent of market change (e.g., changing customer preferences, emerging business opportunities, and demand for new products/services) create critical conditions for innovation (Eisenhardt and Schoonhoven, 1996; Chandler and Hanks, 1994; Rogers, 2003). Attributes of social systems also play a crucial role by shaping environments conducive to innovation. Factors such as prevailing social norms, orientation toward change, the role of change agents, and the structural characteristics of social systems are classified as the Environment Factor (F1).

Second, firms—as the primary actors of innovation—both lead innovation and adopt new technology to diffuse innovation outcomes into other domains. Thus, corporate factors, including organizational characteristics such as firm's size, age, technological capability, internal management capacity, and member attributes (e.g., CEO's entrepreneurship, employee innovativeness) and organizational culture (e.g., shared perceptions, accumulated experience, positive attitude toward creativity, effective communication), have been proposed as influential factors (Porter, 1980; Tornatzky and Fleischer, 1990; Parkhe, 1993; Rogers, 2003; Pollard, 2006). The characteristics of firms—as actors in the conversion process—are classified as Conversion Factor (F3).

Lastly, institutional aspects of society hold a substantial impact on innovation diffusion. More specifically, factors including whether the innovation policy is goal-oriented or service-oriented, whether the government supports innovative initiatives and establishes industrial clusters or networks, and whether the society shares an individualist or collectivist culture are identified as institutional influences on the innovation process (Venkatraman, 1989; Mahler and Rogers, 1999; Rogers, 2003; Lundvall and Borrás, 2005; Hoekman et al., 2005; Ahn and Lee, 2011). Several studies (e.g., Carlsson and Jacobsson, 1994; Bozeman, 2000; Hoekman et al., 2005) have demonstrated that strategic government support and innovation-oriented policy measures contribute to the diffusion of new technology, which is critical for macro-level innovation diffusion. These institutional attributes are classified as the Environment Factor (F1).

These factors—attributes of the market, the social system, firms, and institutions—are summarized in Table 2 below. Most factors driving the diffusion of innovation outcomes to broader domains center on the environment (F1) and the conversion process (F3). The findings suggest that previous macro-level research may not have sufficiently considered technological attributes (F2) when analyzing how innovative outcomes diffuse throughout society.

Table 2. Diffusion Factors Presented in 'Diffusion' Studies

Domain	Dimension	Indicators/Variables	Classification
Market	Market competition	- Degree of market competition - Degree of corporate competition	Environment (F1)
	Market changes	- Changes in customer preferences - New business opportunities - Demand for new product/service	
Social system	Social system	- Social norms - Change orientation - Change agents - Structural characteristics	Environment (F1)
Corporate	Employee characteristics	- CEO's entrepreneurship - Employee innovativeness	Conversion (F3)
	Corporate characteristics	- Size - Age (Year in business) - Technological capability - Degree of internationalization - Internal management capacity	
	Organizational culture	- Shared perceptions - Experience and attitude - Effective communication	
Institution	Policy characteristics	- Goal-oriented/Service-oriented policy	Environment (F1)
	Institutional characteristics	- Industrial clusters/networks - Strategic government support	
	Cultural characteristics	- Individualist/Collectivist culture	

VI. Co-Evolution of Innovation in Technology, Economy, Society, and Policy

1. Integrating Diffusion Factors

The findings from both streams of research can be organized around three categories of diffusion factors proposed by this study: Environment Factor (F1), Technology Factor (F2), and Conversion Factor (F3). Studies focusing on the creation of new technology tend to center on the Technology Factor (F2) and Conversion Factor (F3), while studies emphasizing the diffusion of innovation outcomes across other social domains primarily focus on the Environment Factor (F1) and Conversion Factor (F3).

In other words, from a socio-psychological standpoint, 'innovation' studies—focusing on the narrow innovation process—concern how individuals perceive and adopt new technology. However, they often fail to consider macro-level environmental factors that also exert substantial influence. Conversely, from a business administration perspective, 'diffusion' studies—focusing on the diffusion of innovation outcome—pay greater attention to macro-level environmental factors (e.g., market conditions, social system attributes, institutional aspects) and corporate characteristics. Nevertheless, such studies do not sufficiently examine the specific attributes of the technology being diffused. This gap is illustrated in Figure 3 below.

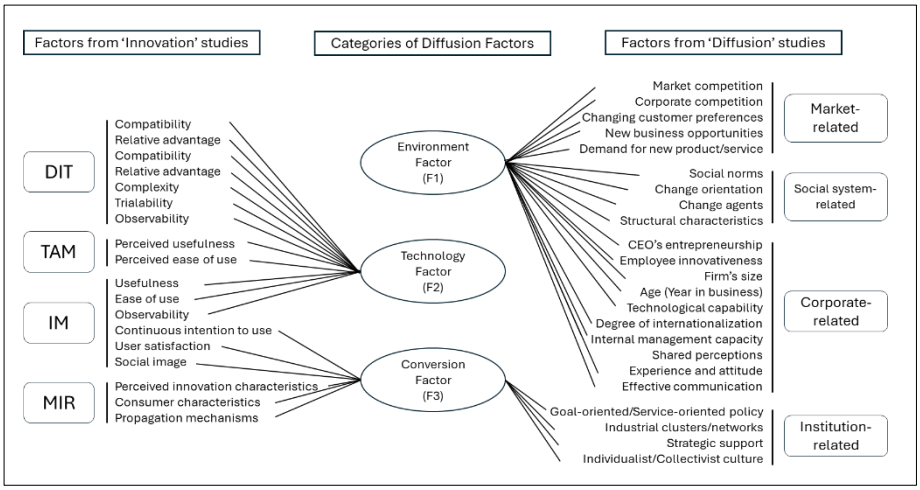

Figure 3. Gap in Innovation Research Identifying Diffusion Factors

To address this gap, the current study integrates findings from both streams of 'innovation' and 'diffusion' studies to gain a deeper understanding of the factors contributing to the diffusion of innovation across different social domains. Recognizing that technological innovation is closely interconnected with innovations in economic, social, and policy domains, the current study proposes a comprehensive list of diffusion factors reflecting the contextual background of the analysis—the recent changes in the innovation environment and technology. Given the array of factors available in the literature, the study relies on the following selection logic. It includes only those factors that meet four criteria: (i) cross-domain generality (i.e., saliency beyond a single technology or sector), (ii) replication across multiple studies or frameworks, (iii) conceptual non-redundancy, and (iv) policy relevance and measurability for diffusion at the macro level. This yields a compact set that remains broad enough to explain

diffusion while precise enough to inform intervention design. Finally, the study proposes a set of propositions regarding the relationships among these factors for future empirical testing.

1.1 Environment Factor (F1)

This factor encompasses the innovation environment surrounding technological innovation, including the economy, society, and institutional domains. The economic environment encompasses paradigms, industrial structures, and processes that facilitate the diffusion of innovation when technology aligns with these economic elements. Recent examples include the paradigm shift toward DX, new industries (e.g., platform businesses), robust innovation networks and collaborations, and transitions toward smart systems in economic activities. The social environment is closely tied to the demand for new technologies, societal perceptions of innovation, evolving social relationships, and a culture that fosters innovation. Innovation diffusion is spurred when technology meets social needs, as evidenced by global challenges (e.g., climate change, pollution, extreme poverty), shifting demands in the labor market and education, the rise of virtual social interactions, and the prevalence of innovative entrepreneurship. Lastly, the institutional environment involves the government's vision, supportive innovation policies, and the establishment of legal frameworks. These institutional elements foster innovation diffusion by providing the necessary support through innovation-oriented decision-making, robust policy measures promoting innovation, and legal reforms that reflect changes in social systems driven by technological innovation. Furthermore, these elements build the foundation for institutional trust—through clear rules, credible standards and certification, transparent governance, and predictable enforcement—which lowers perceived risk for actors adopting innovative technology and complements the individual, social, and organizational trust mechanisms involved in the conversion process identified under the Conversion Factor (F3) (Rogers, 2003; Mahler & Rogers, 1999; Lundvall & Borrás, 2005; Jacobsson & Johnson, 2000).

1.2 Technology Factor (F2)

This factor pertains to the characteristics of the innovative technology being diffused. These characteristics represent general attributes found in the recent innovative technologies that promote innovation diffusion rather than the unique qualities of a specific technology. Many aspects already identified in 'diffusion' studies fall under this category: compatibility, usefulness, versatility, affordance, and generativity. Compatibility refers to whether the new technology can effectively replace an existing one, while usefulness considers its overall value, including economic advantages. Versatility assesses whether technology can be widely applied across different social domains. Affordance denotes the potential

actions technology enables (for example, digital affordance), and generativity describes its capacity to produce unprompted change through recombination or blending with other innovations. Additionally, factors such as ease of use and low cost are important. When new technology is compatible, useful, versatile, easy to use, and low in cost, it is likely to diffuse rapidly and extensively across various domains.

1.3 Conversion Factor (F3)

This factor involves the key actors in the innovation process—individuals, organizations, and society as a whole—who accept, adopt, and apply new technology, thus driving diffusion. The attributes of these actors critically influence the direction and extent of innovation diffusion. At the individual level, innovation diffusion can be driven by innovation-seeking behavior and social influence, with key actors, such as entrepreneurs, playing a pivotal role in championing new technologies. At the organizational level, factors such as an innovation-oriented philosophy, visionary leadership, robust institutional support (e.g., incentives, learning opportunities, innovation networks), and a culture that embraces risk and tolerates failure contribute significantly. At the societal level, diffusion is shaped by open cultural norms, supportive regulatory environments, government policies, effective communication channels, and strong infrastructure that enhances society's overall capacity to learn and adapt. More importantly, across individual, organizational, and societal levels, trust in credible change agents, partner organizations and networks, and institutional rules and oversight consistently reduces perceived risk and resistance, facilitates knowledge exchange, and accelerates the transition from piloting to a dominant design. Thus, trust primarily operates through the conversion process (e.g., leadership credibility, transparent communication, prior collaborative experience), playing a critical role as Conversion Factor (F3). Yet, it is complemented by institutional trust mechanisms identified in Environment Factor (F1), where legal clarity and transparency in governance make the reliability of innovative technology verifiable (Rogers, 2003; Ram, 1987; Ram & Sheth, 1989; Mahler & Rogers, 1999; Jacobsson & Johnson, 2000).

Table 3 below reconfigures a comprehensive list of diffusion factors that reflect the recent changes in the innovation environment and technology driven by digital transformation, building on the previously identified factors from the integrated innovation perspective.

Table 3. Integration of Identified Diffusion Factors of Innovation

Classification	Domain/ Dimension	Key Attributes	Examples
Environment (F1)	Economic environment	- Economic paradigms - Industrial structures - Industrial processes	- Paradigm shift toward digital transformation (DX) - Emergence of new industries (e.g., platform business) - Enhanced innovation networks, collaborations, and transitions to smart systems
	Social environment	- Social demand for technology - Social perceptions of innovation - Evolving social relationships - Culture of innovation	- Global challenges (e.g., climate change, pollution, extreme poverty) - Changing demands for jobs and education - Increased virtual social interactions - Prevalence of innovative entrepreneurship
	Institutional environment	- Government's policy vision - Supportive innovation policies - Relevant legal frameworks - Trust-building mechanisms	- Innovation-oriented decision-making - Robust measures to promote innovation - Creation or revision of laws and regulations (e.g., fair regulations, in-app regulations) - Clear rules/standards, transparent governance, predictable enforcement
Technology (F2)	General characteristics	- Compatibility - Usefulness - Versatility - Affordance - Generativity	- Replacement of existing processes or products - Economic benefits (e.g., cost reduction) - Potential for widespread adoption - Technological potential - Possibility for convergence and fusion

	Usage characteristics	- Ease of use - Low cost of use	- User-friendly design and simplicity - Willingness to pay (e.g., reservation price)
Conversion (F3)	Individual level	- Innovation-seeking behavior - Social influence - Trust in change agents, peers, and technology	- Innovation tendency - Role of innovators or opinion leaders (e.g., entrepreneurs) - Credibility in opinion leaders - Transparent communication
	Organizational level	- Innovation philosophy - Visionary leadership - Robust institutional support (e.g., incentives, learning opportunities, innovation networks) - Culture that embraces risk and tolerates failure - Inter-organizational trust and partner reliability	- Presence of innovative leaders - Incentives for diffusion performance - Participation in innovation networks - Organizational favorability toward risk and failure - Prior collaboration experience - Clear data-governance agreements - Third-party audits
	Societal level	- Openness in cultural norms and attitudes - Supportive regulatory environment and government policies - Effective communication channels - Strong societal infrastructure for learning and adaptation - Trust in institutions, data governance, and technology	- Revisions of laws that hinder diffusion (e.g., Personal Information Protection Law) - Broader policy instruments supporting innovation - Establishing clear standards, independent audits, transparent governance, and privacy/data protection practices

1.4 Proposed Relationships Among Diffusion Factors

Based on the integration of the diffusion factors, the study proposes the following hypotheses regarding the relationships among the three diffusion factors. Technology (F2), including compatibility, usefulness, ease of use, versatility, and generativity, has a positive influence on the speed and breadth of diffusion. Environment Factor (F1), including economic, social, and institutional conditions, moderates this relationship such that supportive and adaptive regimes amplify the effect of F2, while restrictive, constraining regimes dampen it. Conversion Factor (F3), encompassing capabilities, leadership, culture, and networks, mediates the influence of both F1 and F2 by translating technological potential and environmental conditions into the adoption and use of innovative technology.

Within this structure, trust established in the institutional environment (F1), built through clear standards, transparent governance, and credible enforcement, reduces perceived risk and strengthens both the influence of F2 on diffusion and the relationship between F2 and F3 (moderated-mediation), while interpersonal, inter-organizational, and societal-level trust—in change agents, partner networks, and governance—operating through conversion processes (F3) mediates the influences of F1 and F2 on adoption intentions, coordinated implementation, and cross-domain diffusion by lowering perceived risk and easing coordination. Consistent with this, trust-building instruments (F1) increase the realized affordances and generativity of technology (F2) by lowering coordination and compliance costs (Rogers, 2003; Ram, 1987; Ram & Sheth, 1989; Mahler & Rogers, 1999; Jacobsson & Johnson, 2000; Lundvall & Borrás, 2005).

2. Implications for Innovation Policy and the Role of Government

The significance of the study's findings lies in its departure from prior research, which has examined diffusion factors only at a single level or in a fragmented manner. Instead, it categorizes and integrates the factors driving diffusion by considering the interconnections among technology, economy, society, and policy domains, providing a more comprehensive framework.

In particular, the institutional environment under Environment Factor (F1) and the societal attributes under Conversion Factor (F3) underscore the often-overlooked role of government in innovation diffusion. Whereas previous studies have typically focused on technological or environmental characteristics in isolation, the current findings highlight institutional elements (e.g., government support, deregulation) as key factors in diffusion. The emergence of new industries and the transformation of industrial structures and social relationships, driven by technological innovation, call for new legal standards

and norms that are fundamentally different from those of the past. In this regard, the government's proactive role is vital in shaping regulatory frameworks that not only accommodate but also promote rapid technological advancement, ensuring that innovation diffuses effectively across all social domains. Moreover, innovation-oriented policy measures—such as strategic support programs and regulatory reforms—can bridge the gap between technological breakthroughs and their societal adoption, fostering an environment where economic and social benefits are distributed more equitably. Recognizing and harnessing the influence of the policy domain remains essential for steering innovation toward sustainable growth and addressing the challenges of our rapidly evolving social landscape.

Several structural mechanisms help explain why societal and governmental changes consistently lag behind technological and economic advances. Time-scale asymmetry—the "pacing problem"—emerges as scientific and market cycles accelerate while statutory and administrative cycles remain comparatively slow (Marchant, Allenby & Herkert, 2011). Greater uncertainty and irreversibility provide policymakers with real option value (ROV) to delay, rationally slowing rulemaking until information improves (Arrow & Fisher, 1974; Dixit & Pindyck, 1994). Capacity and information asymmetries mean innovators often possess better, timely technical knowledge than regulators and many social actors; closing these gaps requires "technologies of humility" and "systematic evidence" practices (Jasanoff, 2003; OECD, 2012, 2021a). Institutional fragmentation across levels and sectors complicates coordination in multi-level governance (Hooghe & Marks, 2003). Path dependence and legal inertia create increasing returns dynamics that lock in existing arrangements, raising the cost of change (Pierson, 2000). Together, these mechanisms explain the persistent lag highlighted in the current study and the saliency of Environment (F1) and Conversion (F3) Factors relative to Technology Factors (F2).

Nevertheless, governments have a range of policy instruments they can deploy to narrow this lag, primarily operating through Environment (F1) and Conversion (F3) Factors. Consistent with our framework, they can adopt anticipatory, test-and-learn approaches—such as regulatory sandboxes and testbeds—to engage earlier with emerging technologies (Armstrong, Gorst, & Rae, 2019; OECD, 2021b). They can deploy adaptive, principles-based rules with built-in review or sunset provisions to keep regulations current under uncertainty (OECD, 2021a; Gersen, 2007). Governments can mobilize mission-oriented procurement and other demand-pull instruments to accelerate the diffusion into societal domains (Edler & Georghiou, 2007; Mazzucato, 2018). They can leverage standards and certification to coordinate expectations, reduce transaction costs, and enable interoperability (Blind, 2004; Farrell & Saloner, 1985). They should strengthen privacy and data protection and transparent

governance to build trust, a prerequisite for the broad adoption of innovative technology (OECD, 2019; National Institute of Standards and Technology, 2023). Sustained investment in regulatory capabilities and evidence systems (e.g., horizon scanning, regulatory impact assessment, ex-post evaluation) promotes institutional learning (OECD, 2012; OECD, 2021a). For complex, multi-level problems, they can institutionalize cross-agency and coordinate public-private partnerships (Ansell & Gash, 2008). Finally, continuous evaluation should be embedded so that rules and governance improve over time (OECD, 2021a; U.S. Administrative Conference, 2017).

For the benefits of technological innovation to be fully realized, innovation must diffuse throughout the entire social system. Achieving such co-evolution of technology, economy, society, and policy requires both private-sector innovation and concurrent government support. Even when technological and economic innovations are primarily driven by private initiatives, social and policy innovations require government commitment. Thus, managing the tension between these sectors and maintaining a delicate balance becomes even more crucial. Although technological and economic innovations, driven by economic motives, have advanced rapidly, changes in society and government, which must accommodate diverse policy goals and social values, have continued to lag. When technological innovations are introduced into the economy and society, new laws or amendments to existing regulations are required—a process that depends on government initiative and policy support. Paradoxically, these regulations can also constrain innovation. Hence, policy innovation is necessary to avoid obstructing the diffusion of innovative technologies and their applications, and instead to foster innovation and maximize its benefits for the entire social system.

Ultimately, the proposed list of diffusion factors can serve as a foundation for developing government policy. While some factors primarily pertain to private-sector actors, particularly firms in the economic domain, others necessitate deliberate government involvement. Private actors may be reluctant to invest in areas such as pure science and technology, where outcomes are uncertain or not profitable. In this regard, policy innovation is essential, as government measures and support can promote the necessary introduction and widespread adoption of innovations across society, where and when they are desired, thereby fostering innovation across all social domains.

VII. Conclusion

This study presents an integrative framework that overarches the domains of technology, economy, society, and policy to explain how technological innovation diffuses across broader social domains. By synthesizing insights

from both ‘innovation’ and ‘diffusion’ studies, the framework highlights the interconnected nature of innovation and emphasizes the importance of a macro perspective. Given heterogeneity in constructs and outcomes across disciplines, a single pooled effect from a statistical meta-analysis would obscure rather than illuminate macro-level mechanisms. Thus, this study relies on systematic review, narrative synthesis, and qualitative coding instead of statistical aggregation. Also, it proposes a set of testable propositions and offers a list of policy approaches to facilitate targeted empirical validation in future research.

Furthermore, the systematic approach adopted here primarily emphasizes the general components of a system—input, conversion, output, and the environment—which limits its ability to fully capture the intricate interactions and mutual influences among specific actors in the process. Another limitation is that the list of diffusion factors, although more holistic and comprehensive than those presented in previous studies, is primarily derived from a literature review and qualitative analysis. Establishing the relative importance or priorities among these factors remains challenging without empirical validation.

Nevertheless, the proposed framework, which integrates technology, economic, social, and policy domains, advances our understanding of how innovation diffuses and co-evolves within the broader social system. This framework not only highlights the roles of various actors and environmental conditions but also offers actionable insights for policymakers seeking to foster a supportive innovation environment. In particular, the emphasis on the role of government and policy innovation illustrates how innovation-oriented support can bridge the gap between rapid technological advancements and their societal adoption, ensuring that the benefits of innovation are broadly distributed.

Looking ahead, future research should empirically validate the relative importance of the identified diffusion factors through quantitative analyses, refining the framework, and enhancing its practical applicability. Moreover, as DX continues to reshape industries and social relations, further studies should explore how emerging technologies, actors, and evolving policy landscapes interact over time. By doing so, subsequent research can deepen our understanding of the co-evolution of innovations in technology, economy, society, and policy, ultimately contributing to the development of more robust and adaptive innovation systems.

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