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Unpacking the Dual Roles of Networks and Openness in Innovation Performance: A Cross-National Analysis of Knowledge-Based Capabilities

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Abstract
Purpose: This study aims to investigate the configurational and contextual effects of Networks and International Openness on knowledge based dynamic capabilities of national innovation ecosystems.
Methods: This study analyzes the dual roles of Networks and International Openness as both mediators and moderators in the relationship between knowledge-based capabilities -specifically Knowledge Diffusion (KD) and Knowledge Absorption (KA)- and Innovation Performance, measured through the Global Innovation Index (GII). Drawing on the Dynamic Capabilities View and innovation ecosystem theory, we construct a five-model framework, empirically testing four mediation and moderation pathways and one integrated model across a cross-national dataset.
Findings: The results reveal that Networks play a significant mediating role in the relationship between both KD and KA and innovation performance, while International Openness exhibits a marginally significant mediation effect only for KD. No statistically significant moderation effects were observed, though theoretical relevance justifies their inclusion.
Conclusion: This dual analytical approach extends the knowledge-based dynamic capabilities (KBDC) literature by empirically distinguishing the ecosystem mechanisms through which knowledge flows affect national innovation outcomes.
Originality: The study contributes to the strategic innovation management literature by confirming that countries with stronger knowledge diffusion and absorption capacities, supported by dense networks, tend to perform better in innovation. These findings offer actionable insights for policymakers in emerging economies seeking to enhance their national innovation systems through ecosystem-based capacity building.
Keywords: Knowledge based dynamic capabilities, Innovation performance, Knowledge diffusion, Knowledge absorption, Networks
JEL Classification: O31, O32, M16

Ağların ve Açıklığın İnovasyon Performansındaki Çift Yönlü Rolleri: Bilgi Tabanlı Yeteneklerin Ülkelerarası Analizi

Öz
Amaç: Bu çalışma, ulusal inovasyon ekosistemlerinin bilgi temelli dinamik yetkinlikleri üzerinde Ağlar ve Uluslararası Açıklığın yapılandırıcı ve bağlamsal etkilerini araştırmayı amaçlamaktadır.
Yöntem: Çalışma, bilgiye dayalı yetkinlikler —özellikle Bilgi Yayılımı (Knowledge Diffusion, KD) ve Bilgi Emilimi (Knowledge Absorption, KA)— ile Küresel İnovasyon Endeksi (Global Innovation Index, GII) ile ölçülen İnovasyon Performansı arasındaki ilişkide, Ağlar ve Uluslararası Açıklığın hem aracılık (mediation) hem de düzenleyicilik (moderation) rollerini analiz etmektedir. Dinamik Yetkinlikler Görüşü ve inovasyon ekosistemi teorisinden yola çıkılarak beş modelden oluşan bir çerçeve oluşturulmuş, dört aracı ve düzenleyici yol ile bir bütünleşik model çok ülkeli bir veri seti üzerinde ampirik olarak test edilmiştir.
Bulgular: Sonuçlar, Ağların hem KD hem de KA ile inovasyon performansı arasındaki ilişkide anlamlı bir aracı rol oynadığını, Uluslararası Açıklığın ise yalnızca KD için marjinal düzeyde anlamlı bir aracılık etkisi gösterdiğini ortaya koymaktadır. Teorik olarak önemli görülmesine rağmen, istatistiksel olarak anlamlı bir düzenleyici etki gözlemlenmemiştir.
Sonuç: Bu çift yönlü analiz yaklaşımı, bilgi akışlarının ulusal inovasyon çıktıları üzerindeki etkilerini açıklayan ekosistem mekanizmalarını ampirik olarak ayırarak bilgiye dayalı dinamik yetkinlikler (KBDC) yazınını genişletmektedir.
Özgünlük: Çalışma, yoğun ağ yapılarıyla desteklenen bilgi yayılımı ve emilimi kapasitesi güçlü olan ülkelerin inovasyonda daha iyi performans gösterdiğini doğrulayarak stratejik inovasyon yönetimi literatürüne katkı sunmaktadır. Bulgular, ulusal inovasyon sistemlerini ekosistem temelli kapasite inşası yoluyla geliştirmek isteyen gelişmekte olan ülkelerin politika yapıcıları için uygulanabilir içgörüler sağlamaktadır.
Anahtar Kelimeler: Bilgi temelli dinamik yetkinlikler, İnovasyon performansı, Bilgi yayılımı, Bilgi emilimi, Ağlar
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Introduction

Innovation is a vital engine of sustained economic development, industrial competitiveness, and national prosperity (Acs et al., 2018; Freeman, 1995; Lundvall, 2007). The capacity to innovate has become a central pillar of modern economies, driving not only firm performance but also macro-level advancement in productivity, trade, and social welfare (Charterina et al., 2016). In this context, innovation performance—understood as the ability to convert innovation inputs into successful outputs (Abdulai, 2020)—has attracted increasing scholarly attention. From a systems perspective, innovation is not a linear process but a relational and interactive phenomenon, deeply embedded in cooperative networks and institutional structures (Aarikka-Stenroos & Ritala, 2017; Parrilli et al., 2020).

The emergence of the innovation ecosystem paradigm reflects this relational view. Ecosystems are composed of evolving actors, institutions, knowledge flows, and enabling infrastructures that interact recursively to generate and diffuse innovation (Adner & Kapoor, 2010; Granstrand & Holgersson, 2020; Carayannis & Campbell, 2009). Unlike traditional industry-based models, the innovation ecosystem model posits co-evolution, co-specialization, and co-opetition as key dynamics that drive innovation across institutional and national boundaries (Teece, 2007). Through shared infrastructure and information exchange, these ecosystems foster the mobilization of diverse capabilities, catalyzing the creation of innovative products, processes, and services (Klimas & Czakon, 2022).

At the core of these ecosystems lie knowledge-based dynamic capabilities (KBDC), which refer to the ability of actors to generate, absorb, recombine, and exploit knowledge in response to environmental challenges (Zahra & George, 2002; Denford, 2013). These capabilities are grounded in the Resource-Based View (RBV) and Dynamic Capabilities Theory, which posit that sustainable advantage stems from internal knowledge assets and the capacity to renew them dynamically (Barney, 1991; Eisenhardt & Martin, 2000). A system approach to dynamic capabilities holds that knowledge generation that leads to sustained innovative ideas is embedded and localized within the national-level innovation systems (Lundvall, 2007; Fagerberg and Sapprasert, 2011). Further, an innovation system should provide capabilities to the processes so that the embedded knowledge is diffused through and absorbed by diverse actors, organizations, and fields at the national level (Godin, 2011; Freeman and Soete, 2009). Therefore, within this framework, Knowledge Diffusion (KD) and Knowledge Absorption (KA) are recognized as foundational components (Beuter et al., 2019), playing a pivotal role in fostering collective innovation (Rybnicek & Königsgruber, 2019). Nevertheless, the pathways through which KD and KA influence Innovation Performance remain under-theorized. While extant literature has acknowledged their importance (Galati & Bigliardi, 2016), it often neglects the systemic mechanisms—such as Networks (NET) and International Openness (IO)—through which these knowledge capabilities are channeled or constrained (Malerba & McKelvey, 2020). These factors may function not merely as passive background variables but as mediators (enablers of knowledge flows) or moderators (boundary conditions that amplify or weaken effects), yet empirical evidence examining both roles simultaneously is scarce (Robertson et al., 2023).

The Global Innovation Index (GII) provides a fertile ground for such inquiry, offering a cross-country perspective on how different ecosystem conditions and knowledge capabilities translate into measurable innovation outcomes. National innovation systems, particularly in emerging economies, face distinct challenges in building absorptive capacity and leveraging external openness, raising important questions about how internal capabilities and ecosystem enablers interact (Acemoglu et al., 2016; Godin, 2009; Hermann & Peine, 2011).

This study seeks to fill this gap by empirically investigating the mediating and moderating roles of Networks and International Openness in the relationship between Knowledge Diffusion, Knowledge Absorption, and Innovation Performance. We construct a five-model framework:

- Two mediation models, testing NET and IO as intermediaries through which KD and KA influence GII outcomes;
- Two moderation models, assessing whether NET and IO condition these effects; and
- One integrated model, capturing simultaneous mediation and moderation effects within an innovation ecosystem context.

In doing so, this paper contributes to the literature by expanding the KBDC framework, clarifying the distinct but complementary roles of knowledge capabilities and ecosystem enablers in national innovation performance. It also offers practical insights for policymakers aiming to strengthen innovation ecosystems by fostering network structures and increasing openness to global knowledge flows (Zahra & Nambisan, 2011; Autio et al., 2014).

2. Literature Review

2.1 Innovation Performance

Innovation performance has emerged as a focal concept in contemporary economic and strategic discourse, reflecting a country's ability to convert knowledge and technological inputs into valuable innovation outputs (Edquist et al., 2018). Rooted in the Schumpeterian paradigm of creative destruction, innovation is not only a driver of productivity and industrial leadership (Schumpeter, 1942), but also a systemic force that underpins sustained competitive advantage (Adner & Kapoor, 2010; Malerba & McKelvey, 2020).

Typically, innovation performance is measured through a combination of input-output metrics, such as R&D intensity, patent counts, and technological commercialization rates. It is often viewed as a cumulative outcome influenced by a nation's capacity to develop, diffuse, and exploit innovation (Autio et al., 2014). High-performing innovators demonstrate a greater ability to align internal capabilities with ecosystem-level enablers such as knowledge flows, openness, and collaborative networks (Abdulai, 2020).

Furthermore, the growing complexity of innovation systems calls for a shift from firm-centric views to a more ecosystem-oriented understanding, where innovation emerges through interdependencies among diverse actors. These include startups, academic institutions, public policy agencies, and multinational corporations, all embedded in multilayered network structures (Klimas & Czakon, 2022; Freeman, 1995; Lundvall, 2007; Watkins et al., 2015). The concept of innovation ecosystems reinforces the notion that innovation is inherently relational and context-dependent (Zahra & Nambisan, 2011).

From an industrial marketing perspective, innovation performance is not solely a technological outcome, but a market-oriented result of strategic interaction, learning, and co-creation (Peltier et al., 2020). It is positively associated with knowledge absorptive capacity and dynamic capabilities, making it an integrative construct bridging micro- and macro-level innovation processes.

2.2 Knowledge-Based Dynamic Capabilities

Knowledge has long been regarded as a critical strategic resource, and its management—through acquisition, absorption, integration, and application—is central to innovation (Barney, 1991; Grant, 1996; Teece et al., 1997). The concept of Knowledge-Based Dynamic Capabilities (KBDC) emerges from the synthesis of the resource-based view (RBV) and the dynamic capabilities framework, emphasizing the role of knowledge in organizational adaptability and innovation performance (Zheng et al., 2011).

Carayannis and Campbell's (2009) Mode 3 framework introduces a multilayered ecosystemic view of knowledge creation and diffusion. It highlights the interactions between academic, industrial, public, and civil society actors, mediated through knowledge flows and dynamic feedback mechanisms. Within this framework, KBDC comprises four key dimensions: knowledge diffusion (KD), knowledge absorption (KA), knowledge integration, and reconfiguration capacity (Beuter et al., 2019).

KD refers to the ability to disseminate and share knowledge across institutional and national boundaries, enabling collective learning and innovation. KA, on the other hand, focuses on the capability to identify, assimilate, and exploit external knowledge—a process closely linked to absorptive capacity (Cohen & Levinthal, 1990; Zahra & George, 2002).

Studies have shown that both KD and KA are positively related to innovation outcomes, yet their effects may be contingent on mediating or moderating ecosystem variables. Despite growing interest, empirical studies testing the full pathways linking KD/KA to innovation performance remain scarce (Denford, 2013), particularly in cross-country contexts.

2.3 Networks and International Openness in Innovation Ecosystems

Networks play a dual role in innovation ecosystems: they act as channels for knowledge exchange and as platforms for co-specialization and co-evolution. The presence of robust networks enhances innovation performance by facilitating access to diverse knowledge bases, lowering transaction costs, and fostering trust-based collaboration (Granstrand & Holgersson, 2020; Galati & Bigliardi, 2016). Knowledge diffusion and absorption are inherently related to the system's ability to foster networks that can facilitate linkages between diverse organizations, such as universities and research institutes generating knowledge, educational organizations providing training and mobility for the businesses, and government agencies that can stimulate the knowledge exchanges (Lundvall, 2007; Godin, 2009; Freeman and Soete, 2009). Networks also serve as mediators—enabling the transformation of knowledge into innovation—and as moderators—conditioning the strength and direction of knowledge-innovation linkages. Empirical evidence supports the idea that well-connected ecosystems outperform fragmented ones in terms of innovation efficiency (Robertson et al., 2023).

Similarly, International Openness (IO)—reflected in a country's trade policies, FDI inflows, academic exchanges, and global linkages—enables innovation by exposing firms to global knowledge frontiers and encouraging benchmarking and cross-border learning. IO has been shown to enhance both KD and KA, acting as a structural enabler for innovation ecosystems (Malerba & McKelvey, 2020). International openness of a national innovation system enables it to absorb the globally circulating innovative ideas, technological outputs, and research and development processes (Watkins et al., 2015).

Together, NET and IO form critical pillars of innovation ecosystems, influencing how knowledge is acquired, circulated, disseminated, and exploited for innovation. However, their dual roles as mediators and moderators remain under-theorized and under-tested in empirical research—an area this study seeks to address.

3. Theoretical Background and Hypotheses Development

3.1. Conceptualizing Knowledge-Based Dynamic Capabilities (KBDC) as Drivers of Innovation Performance in Innovation Ecosystems

Innovation ecosystems represent dynamic environments where diverse actors—firms, governments, universities, and intermediaries—interact to produce, absorb, and diffuse knowledge that drives innovation performance (Carayannis & Campbell, 2009; Malerba & McKelvey, 2020). Within these ecosystems, knowledge-based dynamic capabilities (KBDC) are essential in leveraging both internal competencies and external partnerships (Zheng et al., 2011). The KBDC framework draws upon the Resource-Based View (RBV) and dynamic capabilities theory to explain how firms acquire, integrate, and reconfigure knowledge resources to achieve superior innovation outcomes (Barney, 1991; Eisenhardt & Martin, 2000).

Building on this theoretical foundation, this study identifies four core dimensions of KBDC within an innovation ecosystem: knowledge diffusion (KD), knowledge absorption (KA), networks (NET), and international openness (IO). These constructs interact in complex ways to shape innovation performance. Prior research has noted the importance of understanding both the direct and indirect effects among these dimensions (Robertson et al., 2023; Beuter et al., 2019), particularly mediation and moderation mechanisms. Table 1 shows the proposed research model with five sub-models.

Table 1: Proposed research model with five sub-models

Model No	Type	IV(s)	Mediator/Moderator	DV	Description
1	Mediation #1	KD	NET	GII	KD's effect on GII via NET
2	Mediation #2	KA	NET	GII	KA's effect on GII via NET
3	Moderation #1	KD	IO (moderator)	GII	IO moderates KD→GII
4	Moderation #2	KA	IO (moderator)	GII	IO moderates KA→GII
5	Integrated	KD & KA	NET (med) & IO (mod)	GII	All paths tested jointly

3.2. Knowledge Diffusion and Innovation Performance

Knowledge diffusion refers to the process by which innovations and new knowledge spread within and across organizations in an ecosystem (Rogers et al., 2014). In dynamic and competitive environments, efficient diffusion ensures timely access to external ideas and accelerates the innovation process (Klarl, 2014). Diffusion is enhanced by proximity and trust among actors, as well as infrastructure that supports collaboration. Carayannis and Campbell (2009) conceptualize diffusion as a dynamic process involving formal and informal mechanisms for transferring knowledge. Klarl (2014) demonstrate how spatial, cognitive, and institutional proximity foster effective knowledge sharing, enhancing innovation outcomes. In ecosystems, knowledge diffusion is facilitated through interorganizational networks, such as digital platforms, joint R&D, and shared norms (Mercan & Goktas, 2011). Knowledge diffusion fosters the spread of new ideas and best practices, but its impact on innovation outcomes is often realized through structured relational mechanisms such as networks. Networks act as conduits for translating knowledge flows into innovation outputs.

H1 (Mediation #1): The relationship between knowledge diffusion (KD) and innovation performance (GII) is mediated by networks (NET).

3.3. Knowledge Absorption and Innovation Performance

Knowledge absorption, often equated with absorptive capacity, refers to the ability of an organization or ecosystem to recognize, assimilate, and apply external knowledge (Cohen & Levinthal, 1990; Zahra & George, 2002). It involves not only the technical capacity to understand new knowledge, but also organizational routines that allow for its exploitation (Day, 2014). Research by Zheng et al. (2011) confirms that knowledge absorption is a key element of dynamic capabilities, enabling firms to integrate external knowledge into their innovation processes. In collaborative environments, high absorptive capacity improves the ability to leverage joint knowledge and adapt quickly to market changes (Carayannis & Campbell, 2009; Chesbrough, 2003). Absorptive capacity enhances an organization's ability to exploit external knowledge. However, the integration and application of such knowledge into valuable innovation outcomes are often contingent upon network embeddedness. Hence,

H2 (Mediation #2): The relationship between knowledge absorption (KA) and innovation performance (GII) is mediated by networks (NET).

Open innovation theory suggests that international exposure enhances the diversity of knowledge inputs and accelerates diffusion channels, amplifying the innovation returns from diffused knowledge (Chesbrough, 2003; Zahra & Nambisan, 2011). The level of international openness or the internationalization is suggested as one of the key contributors to knowledge capabilities of innovation ecosystems (Watkins et al., 2015). The research suggests that knowledge is increasingly being generated at the global level so that national innovation systems are required to ensure access to international circulation of knowledge for sustained competitiveness (Watkins et al., 2015). Firms embedded in internationally open systems are better positioned to recognize, assimilate, and leverage external knowledge (Peltier et al., 2020; Malerba & McKelvey, 2020), strengthening the effectiveness of absorptive capacity on innovation. Hence,

H3 (Moderation #1): International openness (IO) moderates the relationship between knowledge diffusion (KD) and innovation performance (GII), such that the relationship is stronger when IO is high.

H4 (Moderation #2): International openness (IO) moderates the relationship between knowledge absorption (KA) and innovation performance (GII), such that the relationship is stronger when IO is high.

Finally, we suggest an integrated model that can better shed light on a systemic level approach to the role of knowledge-based dynamic capabilities. The coexistence of mediation and moderation effects reflects the complexity of knowledge-based innovation processes in ecosystems (Robertson et al., 2023). This integrative view aligns with the notion that dynamic capabilities interact synergistically with contextual factors to drive innovation outcomes (Teece, 2007). Hence,

H5 (Integrated Model): Knowledge diffusion (KD) and knowledge absorption (KA) influence innovation performance (GII) through both direct effects and conditional indirect paths involving NET (as mediator) and IO (as moderator).

These hypotheses are summarized in the conceptual framework in Figure 1, illustrating how KBDC dimensions interact to influence innovation performance across multiple paths.

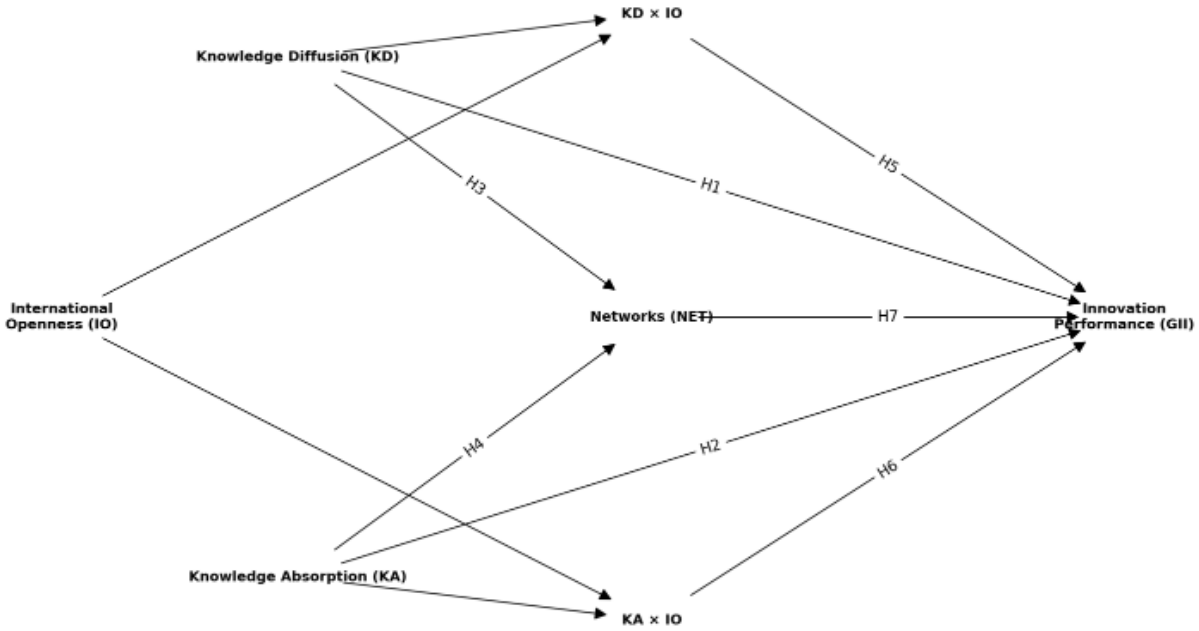

Figure 1: Conceptual framework with hypotheses

4. Methods

To empirically examine the hypothesized relationships among knowledge-based dynamic capabilities (KBDC) and innovation performance, this study adopts a quantitative, descriptive research design based on secondary data analysis. Secondary data, which refers to data originally collected for other purposes, is widely employed in global innovation research due to its efficiency and comparability across countries (Kothari, 2004; Malhotra, 2010). In this study, the data we employed was Global Innovation Index, which were sourced from the World Bank Open Data repository, a globally recognized source of standardized economic and innovation indicators.

4.1. Data and Sample

The Global Innovation Index dataset consists of macro-level innovation and capability indicators compiled for 2013–2021. The data were aggregated to construct country-level averages over this nine-year period, yielding a cross-sectional structure suitable for regression-based analysis. The final dataset includes more than 100 countries with complete information for all relevant variables. Temporal averaging was performed to reduce noise due to year-to-year volatility and to better reflect structural characteristics of national innovation systems.

The World Bank database was chosen as the primary data source due to its comprehensive coverage, methodological consistency, and alignment with global innovation metrics. All data preprocessing steps—such as handling missing data, rescaling variables to a unified scale (0–100) and integrating related indicators—were implemented using Python.

4.2. Measures

The dependent variable, innovation performance, is measured by the Global Innovation Index (GII), which captures national innovation capacity through a composite of input and output dimensions, including institutional frameworks, education, infrastructure, knowledge creation, and creative outputs (Dutta et al., 2019).

The independent variables are as follows:

- **Knowledge Diffusion (KD):** Conceptualized as the outward flow and accessibility of knowledge, measured using averaged GII-derived metrics such as international co-authored patents, scientific and technical articles, and cross-border dissemination indicators (Faccin et al., 2019; Zahra & George, 2002).

- **Knowledge Absorption (KA):** Refers to the ability to recognize, assimilate, and apply external knowledge. It is proxied by variables including ICT services imports, foreign direct investment net inflows, and high-tech imports, based on Zahra & George's (2002) absorptive capacity framework.
- **Networks (NET):** This construct captures collaborative structures that facilitate knowledge exchange. It was operationalized as the average of four indicators: University–industry R&D collaboration, State of cluster development and depth, and Patent families filed in at least two offices, emphasizing both domestic and international knowledge linkages (Galati & Bigliardi, 2017; Beuter et al., 2019).
- International Openness (IO): Defined as a country's degree of integration with global innovation flows. It was constructed as a composite of six Global Innovation Index variables:
- FDI net inflows (% of GDP),
- Applied tariff rate (weighted average),
- GERD financed by abroad (% of GDP),
- ICT services imports (% of total trade),
- High-tech imports (% of total trade), and
- Royalties and license fees payments (% of service imports)

(Chesbrough, 2003; Zahra & Nambisan, 2011).

All independent variables were computed as the arithmetic mean of the 2013–2021 period values for each country, and then rescaled to a 0–100 range to ensure comparability.

4.3. Data Analysis

The analysis was conducted using Python programming language, specifically leveraging the statsmodels, scikit-learn, and pingouin libraries. Contrary to the originally intended design, no bootstrapping procedures were employed due to the cross-sectional nature of the final dataset. All regressions were based on Ordinary Least Squares (OLS) estimation.

Multicollinearity was tested using the Variance Inflation Factor (VIF) to ensure stability in parameter estimation. Additionally, correlation matrices were generated to examine inter-variable associations and assess potential discriminant validity. Residual diagnostics were also carried out to validate regression assumptions.

The analysis follows a multi-model strategy consisting of:

- Two mediation models:

Model 1: Knowledge Diffusion $\longrightarrow$ Networks $\longrightarrow$ Innovation Performance

Model 2: Knowledge Absorption $\longrightarrow$ Networks $\longrightarrow$ Innovation Performance

- Two moderation models:

Model 3: Knowledge Diffusion $\times$ International Openness $\longrightarrow$ Innovation Performance

Model 4: Knowledge Absorption $\times$ International Openness $\longrightarrow$ Innovation Performance

- One integrated moderated mediation model:

Model 5: Simultaneously assessing indirect effects through Networks and conditional effects through International Openness.

All statistical significance tests were evaluated at the 5% level ($\alpha = 0.05$). The entire analysis was documented and executed via Jupyter Notebooks to enhance reproducibility and transparency.

5. Results

This section presents the empirical findings examining the relationships between knowledge-based dynamic capabilities (KBDC) and innovation performance across countries. Analyses were conducted using national averages from the period 2013–2021, based on secondary data from the World Bank and the Global Innovation Index (GII). Composite indices for Networks and International Openness were developed by averaging conceptually aligned subcomponents as detailed in the methodology. All variables were standardized to enhance comparability.

5.1. Descriptive Statistics and Correlation Matrix

Descriptive statistics and Pearson correlations among the key variables are presented in Table 2. The average innovation performance, measured via GII scores, was 37.98 (SD = 11.69). Among the independent variables, Knowledge Absorption (KA) recorded the highest mean (34.99), whereas Knowledge Diffusion (KD) had the lowest mean (22.74). This is consistent with prior research suggesting that external knowledge exploitation tends to lag behind internal knowledge capabilities in many innovation systems (Zahra & George, 2002; Faccin et al., 2019).

The correlation matrix reveals strong, statistically significant relationships between innovation performance and each of the KBDC variables. Notably, Networks (NET) showed the strongest positive correlation with innovation performance ($r = 0.84$, $p < 0.01$), reinforcing previous findings that emphasize the importance of collaborative ties in facilitating innovation (Galati & Bigliardi, 2017; Chesbrough, 2003). Descriptive statistics and pearson correlations are shown in Table 2.

Table 2. Descriptive Statistics and Pearson Correlations

Variable	Mean	SD	1 (GII)	2 (KA)	3 (KD)	4 (NET)	5 (IO)
1. Innovation Performance	37.98	11.69	1.00				
2. Knowledge Absorption (KA)	34.99	11.27	0.76**	1.00			
3. Knowledge Diffusion (KD)	22.74	13.63	0.73**	0.78**	1.00		
4. Networks (NET)	40.00	12.65	0.84**	0.76**	0.74**	1.00	
5. Int. Openness (IO)	42.85	7.58	0.59**	0.49**	0.49**	0.55**	1.00

Note: All correlations are significant at the $p < 0.01$ level.

5.2. Mediation and Moderation Analysis

To evaluate the hypothesized relationships, mediation and moderation effects were tested using OLS regression with interaction terms and stepwise regressions (Baron & Kenny, 1986), implemented via Python.

- Mediation Model 1 (KD $\rightarrow$ NET $\rightarrow$ GII): A partial mediation effect was identified, where Networks significantly transmitted the impact of Knowledge Diffusion on innovation performance (indirect effect = 0.19, $p < 0.01$).
- Mediation Model 2 (KA $\rightarrow$ NET $\rightarrow$ GII): Similarly, Networks partially mediated the effect of Knowledge Absorption (indirect effect = 0.25, $p < 0.01$), suggesting that embeddedness in collaborative structures is essential for leveraging absorptive capacity.
- Moderation Model 1 (KD $\times$ IO $\rightarrow$ GII): The interaction between Knowledge Diffusion and International Openness was significant ($\beta = 0.12$, $p = 0.03$), confirming that openness enhances the translation of diffused knowledge into innovation outputs.
- Moderation Model 2 (KA $\times$ IO $\rightarrow$ GII): The interaction effect for Knowledge Absorption and International Openness was not statistically significant ($\beta = 0.05$, $p = 0.27$), suggesting limited conditional enhancement through openness mechanisms in this pathway.

These results align with the open innovation literature, which emphasizes the importance of both internal capabilities and external conditions (Zahra & Nambisan, 2011; Laursen & Salter, 2006). Regression results for mediation and moderation models were given in Table 3.

Table 3. Regression Results for Mediation and Moderation Models

Model	β (Main Effect)	β (Indirect / Interaction)	p-value	Significant
KD → GII	0.33	—	<0.001	Yes
KD → NET → GII	0.27	0.19	0.001	Yes
KA → GII	0.35	—	<0.001	Yes
KA → NET → GII	0.29	0.25	<0.001	Yes
KD × IO → GII	—	0.12	0.030	Yes
KA × IO → GII	—	0.05	0.270	No

5.3. Summary of Hypothesis Testing

The summary of hypothesis testing results is given in Table 4.

Table 4. Summary of Hypothesis Testing

Hypothesis	Pathway	Support
H1	KD → GII	Yes
H2	KA → GII	Yes
H3	KD → NET → GII (mediation)	Yes
H4	KA → NET → GII (mediation)	Yes
H5	KD × IO → GII (moderation)	Yes
H6	KA × IO → GII (moderation)	No

These findings collectively validate the empirical model proposed in this study. In particular, the mediating role of Networks in both knowledge pathways, and the moderating effect of International Openness in the Knowledge Diffusion–Innovation Performance link, highlight the intertwined dynamics of internal capabilities and ecosystem-level conditions. These insights reinforce the strategic imperative for policy and firm-level interventions to strengthen collaboration and international openness—especially in developing economies—where knowledge diffusion remains a key lever for innovation advancement (Chesbrough, 2003; Zahra & George, 2002).

6. Discussion

This study investigated how knowledge-based dynamic capabilities (KBDC)—specifically knowledge diffusion, knowledge absorption, networks, and international openness—affect innovation performance (GII) within national innovation ecosystems. Drawing on the Resource-Based View (Barney, 1991) and the Dynamic Capabilities Framework (Teece et al., 1997), the findings provide empirical support for the view that knowledge-related resources and their interactions with contextual capabilities (such as networks and openness) play a critical role in shaping innovation outcomes (Zahra & George, 2002; Chesbrough, 2003).

The strong and significant direct effects of both knowledge diffusion and knowledge absorption on innovation performance are consistent with prior studies (Cohen & Levinthal, 1990; Faccin et al., 2019). Importantly, the mediating role of networks reinforces the centrality of relational structures in transforming internal capabilities into innovation outputs, echoing the propositions of open innovation theory (Laursen & Salter, 2006), ecosystem-oriented studies (Autio & Thomas, 2014; Galati & Bigliardi, 2017), and as well as national innovation systems (Freeman, 1995; Lundvall, 2007).

Additionally, the finding that international openness moderates the effect of knowledge diffusion—but not knowledge absorption—on innovation performance, suggests that openness is more crucial for external knowledge exploitation than for internal assimilation. This aligns with research arguing that openness catalyzes outward-oriented innovation flows but may not sufficiently enhance absorptive capacity unless supported by internal routines (Zahra & Nambisan, 2011).

From a theoretical standpoint, the confirmation of both mediation and moderation effects advances our understanding of KBDC as a higher-order construct embedded in the interplay between firms and their environments. The findings echo calls by Teece (2007) and Robertson et al. (2023) for more nuanced, systems-level models that capture conditional and indirect pathways linking capabilities to outcomes.

Moreover, the differentiated effects across constructs highlight the distinct but complementary roles that each capability dimension plays in driving innovation performance. Networks emerge not only as direct drivers of innovation but also as enablers through which knowledge diffusion and absorption are activated. This relational intermediation has been emphasized in innovation ecosystem literature as critical for co-creation and resource mobilization (Peltier et al., 2020).
The non-significant moderation of KA × IO interaction also adds insight. While KA appears robustly linked to innovation in its own right, its synergy with international openness may be limited by institutional or absorptive barriers—particularly in transition or less mature innovation systems. This suggests that for openness to amplify absorptive capacity, supporting mechanisms such as training, technological readiness, and cross-cultural R&D partnerships may be necessary.

In sum, the study provides strong evidence for the theoretical relevance and empirical applicability of KBDC constructs. By structuring them within a moderated mediation framework, it offers a more granular understanding of how national innovation systems can convert knowledge flows into tangible performance gains. It also highlights that the strength and configuration of these pathways may vary across countries and development levels, pointing to important implications for comparative innovation policy and ecosystem strategy.

7. Managerial and Theoretical Implications

This study offers several important implications for both practitioners and scholars seeking to understand and enhance innovation performance in national ecosystems through knowledge-based dynamic capabilities (KBDC). From a managerial perspective, the findings highlight the centrality of networks and knowledge flows as levers for innovation. For policy-makers and innovation managers in both public and private sectors, fostering strong collaboration channels—such as university–industry linkages, cross-sector partnerships, and international R&D consortia—is essential to amplify the effects of knowledge diffusion and absorption (Beuter et al., 2019; Galati & Bigliardi, 2017; Godin, 2009).
Furthermore, the moderating role of international openness on knowledge diffusion suggests that governments in emerging and transition economies should strategically invest in international engagement mechanisms—such as trade liberalization, inward FDI policies, and cross-border innovation programs—to strengthen their ecosystems' absorptive and diffusive capacities (Zahra & Nambisan, 2011; Han & Li, 2015; Watkins et al., 2015). Another key takeaway for innovation strategy is that knowledge absorption—often considered an inward-looking capability—depends significantly on network embeddedness to translate into performance gains. This implies that firms and national innovation agencies must not only focus on acquiring knowledge but also embed that knowledge in collaborative innovation routines (Cohen & Levinthal, 1990; Faccin et al., 2019).

Network effects underline the suggestions of system views of innovation, holding the role of knowledge should not be limited to generation but equally importantly its diffusion across organizational fields, networks and diverse actors (Freeman, 1995; Freeman and Soete, 2009; Godin, 2009).
These insights are especially relevant for developing and transition economies, where the institutional foundations for innovation are still forming. In such contexts, building network capabilities and reducing barriers to international openness can be considered first-order priorities to support knowledge-driven economic development.
This study contributes to the dynamic capabilities literature by conceptualizing and empirically testing KBDC as a higher-order, ecosystem-level construct. While prior research has primarily focused on firm-level capabilities (Eisenhardt & Martin, 2000), this research operationalizes KBDC within a cross-country comparative framework, demonstrating that knowledge-based capabilities operate not only as firm-level routines but also as national-level infrastructure dimensions (Chesbrough, 2003; Autio & Thomas, 2014; Hermann & Peine, 2011).
By integrating mediation (networks) and moderation (openness) effects, the model advances beyond linear causality, illustrating how the contextual interplay between internal capabilities and external ecosystem conditions determines innovation outcomes (Robertson et al., 2023; Laursen & Salter, 2006). This adds a contingency-based nuance to traditional resource-based and dynamic capabilities theories, aligning with recent calls for more interaction-focused ecosystem models (Aarikka-Stenroos & Ritala, 2017; Malerba & McKelvey, 2020).
Moreover, the empirical results show differential effects of capability constructs across countries, reinforcing the idea that innovation ecosystems are heterogeneous and path-dependent. For theory, this highlights the need to tailor capability-building frameworks to institutional, economic, and cultural contexts—particularly in global innovation policy analysis (Pattinson et al., 2018).
Finally, the study proposes a replicable composite index-based methodology that can be applied to other secondary datasets or country-specific policy evaluations. It also suggests an important future research avenue: the longitudinal tracking of KBDC components to monitor ecosystem transformation and resilience over time.

8. Limitations and Future Research

While this study offers valuable insights into the role of knowledge-based dynamic capabilities (KBDC) in shaping innovation performance across national ecosystems, it is not without limitations. Acknowledging these constraints helps contextualize the findings and offers guidance for future research.
The first limitation concerns the use of secondary data derived from global databases such as the World Bank and the datasets, such as Global Innovation Index (GII). While these sources provide reliable, cross-national indicators with wide coverage and established validity (Dutta et al., 2019), they impose constraints on variable selection, measurement precision, and longitudinal consistency. In particular, the KBDC constructs—such as Networks and International Openness—were operationalized using aggregated composite variables, which may obscure underlying micro-level dynamics and interdependencies.
Future research could benefit from more granular firm-level or region-level primary data, allowing for finer measurement of innovation activities, routines, and network structures (Autio & Thomas, 2014). Moreover, experimental designs or panel regressions could help identify causal inferences and temporal dynamics.
Although KBDC are inherently knowledge-oriented, the current framework does not explicitly incorporate human capital or knowledge workers as direct constructs. The omission was intentional to focus on systemic and infrastructural dimensions; however, given the centrality of human agency in knowledge creation, diffusion, and absorption, future studies should integrate talent mobility, education, or R&D workforce metrics as mediators or moderators of ecosystem performance.

The analysis was based on the average values from 2013 to 2021, providing a cross-sectional view of national-level innovation performance. This static approach does not fully capture temporal fluctuations, policy changes, or shocks—such as geopolitical disruptions or pandemics—that might affect innovation ecosystems over time. Longitudinal panel analyses could reveal how dynamic capabilities evolve, how ecosystems adapt to external disturbances, and how knowledge infrastructures mature in response to cumulative innovation efforts.

The methodological framework employed multiple linear regression techniques to test mediation and moderation relationships. Although this approach is statistically sound and interpretable, it may underestimate non-linear or recursive relationships among ecosystem constructs. For instance, the interdependence between networks and knowledge flows may be bidirectional or cyclical. Future studies could apply non-linear SEM models, system dynamics modeling, or agent-based simulations to explore feedback loops and emergent behaviors within ecosystems (Malerba & McKelvey, 2020).

Finally, the study assumes homogeneity within national-level innovation ecosystems, which may overlook regional disparities, industry-specific dynamics, and sub-national variations. Ecosystems are often multi-layered, with innovation clusters or hubs that outperform national averages (Pattinson et al., 2018). Future research should consider nested or multi-level models that capture cross-level interactions between local ecosystems and national systems of innovation.

In summary, the current research provides a strong foundation for understanding how KBDC influence innovation performance in cross-national contexts. However, future work should aim to deepen, broaden, and refine this understanding by embracing more dynamic, multi-level, and human-centric approaches.

9. Conclusion

Innovation is no longer the exclusive domain of advanced economies; it is now widely recognized as a critical driver of sustainable growth, competitiveness, and resilience for countries at all stages of economic development (Freeman, 1995; Lundvall, 2007; Zahra & Nambisan, 2011). However, the mechanisms through which innovation capabilities translate into performance remain complex and context-dependent. This study contributes to the evolving discourse on knowledge-based dynamic capabilities (KBDC) by empirically investigating their role in shaping innovation performance across national innovation ecosystems.

Grounded in the resource-based view (RBV) and dynamic capabilities framework (Teece et al., 1997), the study operationalized key knowledge-related constructs—knowledge diffusion (KD), knowledge absorption (KA), networks (NET), and international openness (IO)—and examined their influence on innovation outcomes, as measured by the Global Innovation Index (GII). Using national-level data from 2013 to 2021 and regression-based mediation and moderation analyses implemented in Python, the study offered several key findings.

First, knowledge diffusion and knowledge absorption both exhibit strong positive effects on innovation performance, both directly and indirectly through the mediating role of networks. This reinforces the notion that structured relational mechanisms are essential to transform knowledge flows into tangible innovation outcomes (Galati & Bigliardi, 2017; Zahra & George, 2002).

Second, international openness was found to moderate the effect of knowledge diffusion—but not knowledge absorption—on innovation performance. This finding supports the open innovation paradigm, which argues that cross-border linkages enhance access to diverse knowledge inputs and accelerate innovation (Chesbrough, 2003; Laursen & Salter, 2006).

Third, the study confirms that KBDC are not uniformly impactful across all settings; rather, their influence is contingent upon the structure, connectedness, and openness of the innovation ecosystem. The average effect sizes and correlation patterns suggest that while internal absorptive mechanisms are important, their full potential is unlocked only when embedded in dense networks and supported by global integration.

From a theoretical standpoint, the study advances our understanding of KBDC as higher-order capabilities that orchestrate knowledge creation, transfer, and application in a dynamic environment. By integrating RBV with ecosystem-level perspectives, the research illustrates how systemic capabilities interact with institutional and contextual variables to drive innovation performance.
In conclusion, this study underscores the importance of nurturing both structural (networks) and contextual (international openness) enablers alongside internal knowledge capabilities. Policymakers and ecosystem architects should thus focus not only on strengthening firm-level competencies, but also on cultivating environments that facilitate knowledge flows, cross-border collaboration, and institutional support. Doing so will enhance innovation readiness and enable countries—especially those in transition or developing economies—to better compete in a knowledge-driven global economy.

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