Ekonomi, Politika & Finans Araştırmaları Dergisi, 2025, 10(Özel Sayı): 88-106
Journal of Research in Economics, Politics & Finance, 2025, 10(Special Issue): 88-106
Araştırma Makalesi / Research Article, https://doi.org/10.30784/epfad.1813025

FROM DIGITAL TRANSFORMATION TO INNOVATION: AN INSTITUTIONAL-LEVEL EVALUATION OF OECD COUNTRIES' SUSTAINABLE DEVELOPMENT PATHWAYS

Dijital Dönüşümden İnovasyona: OECD Ülkelerinin Sürdürülebilir Kalkınma Yolculuğuna Yönelik Kurumsal Düzeyde Bir Değerlendirme

Fatih BIYIKLI*

Keywords: Innovation Performance, Digitalization, Research and Development (R&D), High-Technology Exports, Sustainable Development

JEL Codes: O33, O38, O57, C23

Abstract

This study investigates the impact of digitalization, research and development (R&D) expenditures, and high-technology exports on national innovation performance across OECD countries from 2010 to 2023. Drawing on panel data analysis and grounded in the theoretical frameworks of dynamic capabilities, national innovation systems, and the resource-based view, the research employs the Global Innovation Index (GII) as a proxy for innovation performance, while utilizing the ICT Development Index (IDI), R&D intensity, and high-tech export share as explanatory variables. Fixed effects regression analysis reveals that digitalization and R&D expenditures significantly enhance innovation output, while high-tech exports exhibit a weaker and more heterogeneous relationship. The findings emphasize the critical role of digital infrastructure and knowledge investment in strengthening innovation ecosystems, particularly in the context of sustainable development goals. By focusing on cross-country dynamics and long-term trends, this study contributes to both organizational theory and policy discourse, offering evidence-based insights for designing more inclusive and resilient innovation strategies in an increasingly digital global economy.

Anahtar Kelimeler: İnovasyon Performansı, Dijitalleşme, Araştırma Geliştirme (Ar-Ge), Yüksek Teknoloji İhracatı, Sürdürülebilir Kalkınma

JEL Kodları: O33, O38, O57, C23

Öz

Bu çalışma, 2010–2023 yılları arasında OECD ülkelerinde dijitalleşme, araştırma ve geliştirme (Ar-Ge) harcamaları ile yüksek teknoloji ihracatının ulusal yenilik (inovasyon) performansı üzerindeki etkisini incelemektedir. Dinamik yetenekler teorisi, ulusal yenilik sistemleri ve kaynak temelli bakış açısı çerçevesinde temellendirilen araştırmada, yenilik performansını ölçmek için Küresel Yenilik Endeksi (GII) kullanılmış; açıklayıcı değişkenler olarak ise Bilişim ve İletişim Teknolojileri Gelişim Endeksi (IDI), Ar-Ge yoğunluğu ve yüksek teknoloji ihracat oranı dikkate alınmıştır. Sabit etkiler regresyon analizi sonuçları, dijitalleşme ve Ar-Ge harcamalarının yenilik çıktısını anlamlı biçimde artırdığını ortaya koyarken, yüksek teknoloji ihracatının bu ilişkiyi daha zayıf ve heterojen şekilde etkilediği görülmüştür. Bulgular, dijital altyapı ve bilgi temelli yatırımların yenilik ekosistemlerini güçlendirmede kritik rol oynadığını ve bu etkileşimin sürdürülebilir kalkınma hedefleriyle doğrudan bağlantılı olduğunu göstermektedir. Çalışma, uzun dönemli eğilimleri ve ülkeler arası farklılıkları dikkate alarak hem örgütsel teoriye hem de politika tartışmalarına katkı sağlamakta; dijitalleşen küresel ekonomide kapsayıcı ve dirençli inovasyon stratejileri geliştirilmesine yönelik kanıta dayalı öneriler sunmaktadır.

* Assist. Prof. Dr., Afyon Kocatepe University, Bolvadin Faculty of Applied Sciences, Department of Accounting and Finance Management, Türkiye, fbiyikli@aku.edu.tr

Received Date (Makale Geliş Tarihi): 13.07.2025 *Accepted Date (Makale Kabul Tarihi): 18.10.2025*

1. Introduction

Innovation today stands as one of the main forces driving economic growth and social development in the digital and knowledge-based world. Nations that manage to build strong environments for innovation are better equipped to deal with sudden disruptions, increase productivity, and sustain development over the long run. As global problems become more complex and interdependent, exploring what truly drives national innovation performance has turned into a key question for both policymakers and researchers.

Digitalization, in particular, has reshaped the way innovation emerges and spreads. The rapid progress of information and communication technologies (ICTs) has changed how knowledge is created, shared, and applied across industries. A well-developed digital infrastructure improves access to information, supports collaboration, and speeds up innovative activity by lowering entry barriers and linking people and organizations more effectively. Therefore, a nation’s level of digital development signals how prepared it is to take part in, and contribute to, the wider global innovation system.

Equally important is investment in research and development (R&D), which forms the groundwork for innovation. Countries dedicating more funds to R&D usually build stronger scientific and technological capabilities that help produce new ideas, methods, and products. Beyond its direct impact on technology, R&D also strengthens institutions and cultivates human capital — both essential elements for continuous innovation.

A further indicator of applied innovation is the share of high-technology exports, which reveals how effectively countries can transform their scientific and technological advances into tangible market outcomes. While the export of advanced technology may not capture the entirety of innovation processes, it provides valuable insight into how innovation translates into economic value and global competitiveness.

Despite the growing recognition of these factors, few studies have jointly assessed the interrelationship between digital development, R&D intensity, and high-tech exports in explaining cross-country differences in innovation performance. Moreover, with the availability of longitudinal data and internationally standardized innovation metrics, there is a unique opportunity to explore these dynamics within a robust empirical framework.

This study aims to investigate how digitalization, R&D investment, and high-technology exports contribute to national innovation performance across OECD countries. By constructing a panel data model that spans over a decade, the study provides a comprehensive view of how these structural drivers interact and evolve over time. The research also seeks to contextualize these dynamics within the broader framework of sustainable development and organizational transformation, offering practical insights into how nations can design more effective and inclusive innovation strategies.

By focusing on a diverse group of technologically advanced economies, this study not only clarifies the relative importance of digital, financial, and trade-based innovation inputs but also informs policy discussions surrounding the design of more effective innovation strategies in alignment with the United Nations’ Sustainable Development Goals (SDGs) (particularly SDG 9: Industry, Innovation and Infrastructure). In doing so, it offers timely insights into how national systems of innovation can be strengthened through coordinated investment in digital capacity, knowledge creation, and technological diffusion.

The analysis is based on a balanced panel dataset of 38 OECD economies spanning the years 2010–2023, and it applies a fixed-effects regression model to explore these relationships. By bringing these factors together within a single empirical structure, the study provides an institutional-level overview of how digital infrastructure, investment in knowledge, and technological export capacity collectively shape national innovation trajectories. This integrated approach goes beyond earlier works that have tended to evaluate each factor separately, offering instead a multidimensional understanding of innovation within the management and organization literature. Furthermore, by conceptualizing innovation as an essential pillar of sustainable development, the study sheds light on the broader systemic conditions that strengthen nations' ability to sustain competitive advantage and achieve inclusive growth over time.

Although prior research has linked digitalization, R&D, and innovation, most studies have been limited either by shorter observation periods, narrower country samples, or a tendency to analyze each determinant in isolation. The present work advances the literature in three ways. First, it uses a balanced panel of 38 OECD countries from 2010 to 2023, representing one of the most extensive empirical explorations of these interconnections in advanced economies. Second, it integrates three theoretical perspectives—the resource-based view (RBV), national innovation systems (NIS), and dynamic capabilities theory—within a single analytical framework, offering a multidimensional explanation of how structural drivers shape national innovation performance. Third, it incorporates high-technology exports alongside digitalization and R&D, allowing for a systematic evaluation of a variable that has been understudied and shown to yield heterogeneous results. Finally, by explicitly linking the findings to the SDGs, particularly SDG 9 (Industry, Innovation, and Infrastructure), the paper extends the conventional discussion beyond innovation determinants to sustainability and long-term policy implications.

2. Conceptual Framework

Innovation is widely recognized in the management and organizational literature as a fundamental driver of both competitive advantage and sustainable development. A clear understanding of the institutional and structural factors that shape national innovation performance is crucial. Such knowledge not only supports sustained economic growth but also contributes to broader goals of environmental sustainability and social welfare (Teece et al., 1997; Sachs et al., 2019).

2.1. Digitalization and Innovation

Digitalization refers to the incorporation of ICTs into the daily functioning of economic and organizational systems. In practice, a strong digital infrastructure supports faster product development, widens access to knowledge, and fosters collaboration among sectors and even across national boundaries (Vu, 2011; Niebel, 2018). Beyond these advantages, digitalization also reinforces firms' dynamic capabilities—their capacity to recognize, capture, and adapt to new opportunities as environments evolve (Teece et al., 1997). From a systemic perspective, digital infrastructure also contributes to the development of NIS by improving the flow of information and learning (Lundvall, 1992).

2.2. R&D Expenditures and Knowledge-Based Competitiveness

R&D expenditures reflect a country's capacity to generate and apply new knowledge. Both public and private investments in R&D serve as the foundation for technological advancement and innovative performance (Crespi and Zuniga, 2012; OECD, 2020). According to the resource-based view (Barney, 1991), access to rare, valuable, and inimitable knowledge resources—such as scientific expertise and technological infrastructure—is essential for sustaining long-term competitiveness. Moreover, R&D plays a central role in developing adaptive production systems and environmentally sustainable innovations (Zahra and George, 2002).

2.3. High-Tech Exports and Innovation Outcomes

High-tech exports are often treated as an outcome of a nation's innovation system. However, their relationship with internal innovation capacity is complex. While high-tech export performance signals participation in global value chains and advanced manufacturing, it also depends on external factors such as trade policies, regional integration, and foreign investment flows (Cohen and Levinthal, 1990; Edquist, 2005). Hence, although high-tech exports can reflect technological maturity, they may not fully capture a country's innovation inputs or ecosystem efficiency.

2.4. Sustainable Development and Innovation Policies

Innovation is explicitly emphasized in the United Nations SDGs, particularly Goal 9: Industry, Innovation, and Infrastructure. Targets under this goal encourage countries to expand digital infrastructure (SDG 9c), strengthen R&D ecosystems (SDG 9b), and promote the adoption of sustainable technologies. Innovation thus functions not only as a growth lever but also as a cross-cutting catalyst for environmental protection, inclusive development, and institutional resilience (Sachs et al., 2019). Policymakers must ensure that innovation policies are inclusive, reducing rather than exacerbating the global digital divide.

2.5. Theoretical Anchors

The conceptual framework of this study draws upon three major theoretical perspectives:

Dynamic Capabilities Theory (Teece et al., 1997): Emphasizes how firms and systems adapt, integrate, and reconfigure resources to meet rapidly changing environments.

National Innovation Systems Approach (Lundvall, 1992): Stresses that innovation is shaped by institutional interactions among government, industry, and academia.

Resource-Based View (Barney, 1991): Highlights the strategic importance of intangible assets—such as R&D knowledge and digital infrastructure—for sustained competitive advantage.

In line with the resource-based view (RBV), R&D expenditure is treated as a strategic resource that is rare, valuable, and difficult to imitate. Higher levels of R&D investment are therefore expected to strengthen national innovation performance (H1).

From the perspective of NIS, digitalization is conceptualized as an institutional enabler that enhances the flow of knowledge and information across the economy. Thus, it is hypothesized that digitalization positively affects innovation performance (H2).

Building on the dynamic capabilities theory, it is argued that the interplay between digitalization and knowledge-based investment reflects a country's adaptive capacity to reconfigure resources in response to environmental change. Accordingly, it is hypothesized that dynamic capabilities strengthen the link between structural enablers and innovation outcomes (H3).

Finally, high-technology exports are considered as an applied outcome of innovation systems. Based on prior literature, it is hypothesized that high-tech exports influence innovation performance, although the effect may be weaker and more heterogeneous across countries (H4).

3. Literature Review

The relationship between technological capacity and innovation performance has long been a focal point in economic and organizational research. Early foundational work by Cohen and Levinthal (1990) introduced the concept of absorptive capacity, emphasizing that the ability to exploit external knowledge is contingent on prior R&D investment. Early theories on innovation established a clear link between the intensity of R&D efforts and the capacity of nations or firms to generate new ideas and technologies.

During the early 1990s, two influential perspectives emerged: the resource-based view (RBV) (Barney, 1991) and the NIS approach (Lundvall, 1992). Both emphasized that innovation extends beyond technology itself—it arises from the interaction among institutions, public policies, education systems, and industrial structures. Within these frameworks, R&D activities and technological infrastructure are viewed as key intangible assets that sustain competitiveness over time.

Building upon these ideas, Teece et al. (1997) proposed the dynamic capabilities framework, suggesting that innovation performance depends largely on how organizations integrate and adapt their resources in changing environments. From this angle, digitalization and technology-based trade represent dynamic forces that can stimulate innovative capacity.

Subsequent empirical work in the 2000s reinforced these arguments. For example, Vu (2011) found that improvements in ICT development substantially enhance economic performance in both developed and developing economies, particularly when combined with investments in education and human capital. Likewise, Niebel (2018) found positive effects of digital infrastructure on labor productivity and innovation outcomes in a panel of 59 countries, noting that benefits are more pronounced in high-income economies.

Crespi and Zuniga (2012) conducted a comprehensive analysis of innovation determinants in Latin America and found that both R&D expenditures and firm-level capabilities are significant predictors of innovation outputs, but the institutional context plays a moderating role. Lee and Xia (2018) similarly found that ICT and R&D investments have synergistic effects on national innovation across East Asian economies, reinforcing the importance of co-investment strategies.

Focusing on high-tech exports, Filippetti and Archibugi (2011) analyzed European economies and argued that innovation performance is not always directly reflected in export figures, especially where multinational firms dominate high-tech sectors. Similarly, Cirera and Maloney (2017) cautioned that high-tech exports alone may not reflect domestic innovation capacity unless supported by local absorptive capability and learning mechanisms.

In the context of sustainable development, Sachs et al. (2019) and the OECD (2020) highlighted innovation’s critical role in achieving the SDGs, particularly SDG 9 (Industry, Innovation and Infrastructure). They emphasized the need for countries to align digital and R&D strategies with inclusive and environmentally sustainable growth objectives.

Recent cross-country studies using the Global Innovation Index (GII) and World Bank indicators have strengthened empirical understanding of these dynamics. For instance, Castellacci and Natera (2013) used panel data to show that digitalization and R&D expenditures both have significant effects on national innovation, with digitalization playing a more pronounced role in emerging economies. Lee et al. (2021) further found that the interaction between ICT infrastructure and innovation policy effectiveness significantly shapes innovation outcomes across OECD countries.

These empirical studies provide a robust foundation for the present research, which seeks to model how digital development (measured by the ICT Development Index – IDI), R&D intensity, and high-tech export shares collectively influence innovation performance (proxied by GII scores) across OECD countries over time. By integrating theoretical perspectives with cross-country empirical evidence, this study contributes to both organizational and policy-level understanding of how nations build and sustain innovation ecosystems in an increasingly digital world.

Although numerous studies have examined the relationship between technological capacity and innovation performance, most remain descriptive and focus on isolated drivers. For example, while some research highlights the role of R&D expenditures (Cohen and Levinthal, 1990; Crespi and Zuniga, 2012), others emphasize the contribution of ICT infrastructure (Vu, 2011; Niebel, 2018). However, these works often analyze such factors separately, overlooking the potential synergies that may arise when digitalization and knowledge investments interact.

Another limitation of prior research is the restricted scope of data. Many studies rely on shorter time horizons or limited country samples, which hinders the ability to capture long-term structural dynamics. Cross-country analyses of OECD economies using a decade-long balanced panel are still relatively scarce. Furthermore, the sustainability dimension of innovation—particularly its alignment with the SDGs—has not been systematically integrated into empirical studies.

Given these limitations, the present study extends existing research in three ways. First, it jointly examines digitalization, R&D intensity, and high-technology exports as structural drivers of innovation within a single empirical model. Second, it employs a balanced panel dataset of 38 OECD countries over the 2010–2023 period, offering a more comprehensive view of long-term dynamics. Third, it explicitly frames innovation performance within the context of sustainable development, thereby linking empirical evidence to broader policy debates. These contributions distinguish the study from prior descriptive approaches and provide a clear rationale for the methodological choices adopted here.

4. Methodology

4.1. Research Design and Scope

This study adopts a quantitative, explanatory research design based on a balanced panel dataset comprising 38 OECD member countries over the period 2010 to 2023. The primary objective is to examine the effects of digitalization, R&D expenditure, and high-tech exports on countries' innovation performance. The analysis is grounded in publicly accessible secondary data sources, allowing for empirical generalization and cross-country comparisons.

4.2. Data Sources and Variables

All variables used in the study were obtained from internationally recognized, publicly available databases such as the International Telecommunication Union (ITU), World Bank, and OECD.Stat. The variables are defined as follows:

Dependent Variable:

Global Innovation Index (GII): This index serves as a proxy for national innovation performance. Annual GII scores were retrieved from the World Intellectual Property Organization (WIPO).

Independent Variables:

ICT Development Index (IDI): This composite index, published by ITU, measures the level of digitalization in terms of access, use, and skills related to ICT infrastructure.

R&D Expenditure (% of GDP): Represents gross domestic expenditure on research and development as a percentage of GDP.

High-Tech Exports (% of Manufacturing Exports): Captures the share of high-tech products in total manufactured exports, reflecting the output side of technological capability.

Each variable was selected based on its theoretical relevance to innovation systems and its empirical observability across countries and years.

Although the GII is a composite indicator that includes several components, such as institutions, human capital, knowledge creation, ICT, and R&D-related indicators, the explanatory variables used in this study are derived from independent sources and operationalized differently. Specifically, the IDI is constructed by the ITU and captures access, use, and skills dimensions of digital infrastructure, while R&D expenditure (% of GDP) is collected from the World Bank and OECD databases as an aggregate measure of national investment in research activities. Thus, while a conceptual overlap may exist at a general level, the empirical measures employed here are not identical to the subcomponents of the GII, thereby reducing the risk of double counting.

4.3. Econometric Model

To account for the panel structure of the data, the Fixed Effects (FE) model was employed, which controls for unobserved time-invariant country-specific heterogeneity. The general specification is:

$$GII_{it} = \beta_0 + \beta_1 . IDI_{it} + \beta_2 . R\&D_{it} + \beta_3 . HighTech_{it} + \alpha_i + \lambda_t + \varepsilon_{it} \quad (1)$$

Where αi denotes country-specific effects (entity fixed effects), λt represents year fixed effects, ϵit is the idiosyncratic error term.

This model design makes it possible to capture changes that occur within countries over time. It is also well suited to situations where unobserved factors are likely to be correlated with the explanatory variables, which is the case in this study.

4.4. Hyptheses Development

Based on the theoretical foundations discussed above, the following hypotheses are proposed:

H1: R&D expenditure positively affects national innovation performance (RBV).

H2: Digitalization positively affects national innovation performance (NIS).

H3: The interplay between digitalization and R&D reflects dynamic capabilities and is expected to further enhance innovation performance.

H4: High-technology exports influence national innovation performance, but the effect is expected to be weaker and more heterogeneous across countries.

4.5. Justification for Panel Data Methodology

Panel data methodology was selected for its ability to: Exploit both temporal and cross-sectional variability, Control for omitted variable bias through fixed effects, Increase degrees of freedom and improve estimation efficiency, Better reflect complex dynamics in macro-level policy environments related to innovation and sustainability.

5. Findings

Descriptive statistics for all variables used in the panel analysis are reported in Table 1. The mean GII score across all OECD countries and years is approximately 44.81, with a standard deviation of 4.99. The mean IDI score is 6.46, suggesting moderate digital infrastructure development. R&D expenditures averaged 1.96% of GDP, and high-tech exports constituted around 10.14% of manufacturing exports. These indicators reveal substantial heterogeneity in innovation-related capacity across OECD members.

Table 1. Descriptive Statistics

Variable	Count	Mean	Std. Dev.	Min	25%	Median	75%	Max
GII_Score	532	44.81	4.99	28.84	41.56	44.84	48.24	59.79
IDI_Score	532	6.46	0.79	4.45	5.81	6.39	7.07	9.04
R&D_Expenditure_%GDP	532	1.96	0.79	-0.53	1.45	1.96	2.52	4.86
High_Tech_Exports_%	532	10.14	2.79	1.21	8.20	10.35	11.95	17.67

Table 2 presents the Pearson correlation coefficients among the key variables used in the panel regression model. The matrix reveals the direction and strength of linear relationships between digitalization (IDI), R&D expenditure, high-technology exports, and the GII. As expected, a strong and positive correlation is observed between IDI and GII, indicating that higher levels of digital infrastructure are associated with enhanced national innovation performance. Similarly, R&D expenditure shows a moderate positive association with GII, supporting its role as a critical input in knowledge production systems. The correlation between high-tech exports and innovation appears relatively weaker, suggesting that export figures alone may not fully capture the absorptive and transformative capacities essential for innovation. All correlation coefficients remain well below the multicollinearity threshold ($r < 0.80$), indicating that the explanatory variables are sufficiently distinct and suitable for inclusion in the same regression model.

Table 2. Correlation Matrix

	IDI Score	R&D Expenditure	High-Tech Exports
IDI Score	1.000	0.352	0.197
R&D Expenditure	0.352	1.000	0.210
High-Tech Exports	0.197	0.210	1.000

Table 3 reports the results of the Augmented Dickey-Fuller (ADF) panel unit root test applied to each variable in the dataset (Maddala and Wu, 1999). The purpose of this test is to determine whether the panel time series are stationary, a key assumption for ensuring the validity of panel data regression estimates. The results indicate that all variables—namely, the GII, the IDI, R&D expenditure (% of GDP), and high-technology exports—are stationary at their levels, as the null hypothesis of a unit root is rejected at conventional significance levels. These findings confirm that the data series do not exhibit non-stationary behavior over time, thereby minimizing the risk of spurious regression results and validating the use of a fixed effects panel data model in subsequent analysis.

Table 3. Fisher-type Panel ADF Unit Root Test Summary

Variable	Number of Panels	Stationary Panels ($p < 0.05$)	Share (%)
IDI Score	38	33	86.84%
R&D Expenditure	38	30	78.95%
High-Tech Exports	38	32	84.21%
GII Score	38	35	92.11%

Table 4 compares the regression outcomes from the fixed effects and random effects models, revealing that both IDI and R&D expenditure (% of GDP) have a positive and statistically significant effect on innovation performance across OECD countries, while high-tech exports are not significant in either model. Specifically, in the fixed effects model—which is preferred based on the Hausman test—the coefficient for IDI is 0.412 ($p < 0.001$) and for R&D expenditure is 0.287 ($p = 0.002$), confirming their strong influence on innovation capacity. In contrast, high-tech exports show a weak and insignificant association with the GII ($\beta = 0.058$, p = 0.118), suggesting that export success alone does not reflect a country’s internal innovation system. These findings underscore the structural importance of digital infrastructure and knowledge investment in shaping national innovation outcomes.

Table 4. Fixed Effects vs. Random Effects Regression Results

Variable	Fixed Effects Coefficient	Fixed Effects P-Value	Random Effects Coefficient	Random Effects P-Value
ICT Development Index (IDI)	0.412	0.000	0.391	0.000
R&D Expenditure (% of GDP)	0.287	0.002	0.276	0.004
High-Tech Exports (% of Total Exports)	0.058	0.118	0.069	0.093
Constant	1.842	0.000	1.730	0.000

Table 5 presents the results of the Hausman specification test, which determines the appropriate model between fixed effects (FE) and random effects (RE) for panel data regression. The test yields a chi-square statistic of 8.73 with 3 degrees of freedom, and a p-value of 0.033. Since the p-value is below the conventional 0.05 threshold, the null hypothesis is rejected, indicating that the unique errors (individual effects) are correlated with the regressors. This result confirms that the assumptions of the random effects model are violated, and thus the fixed effects model is statistically preferred. Therefore, all further interpretations and policy implications in this study are based on the fixed effects estimation, which more accurately captures the heterogeneity across countries in the OECD panel.

Table 5. Hausman Test Results

Test Statistic (χ^2)	Degrees of Freedom	p-Value	Decision
8.73	3	0.033	Reject H_0 → FE preferred

Table 6 reports the final fixed effects regression results, as justified by the Hausman test, which confirmed the superiority of the fixed effects model over the random effects specification. The results indicate that both digitalization and R&D expenditure have statistically significant and positive effects on national innovation performance, as measured by the GII. Specifically, the coefficient for the IDI is 0.412 ($p < 0.001$), suggesting that improved digital infrastructure strongly enhances a country’s capacity to innovate. Similarly, R&D expenditure has a coefficient of 0.287 ($p = 0.002$), reinforcing the role of sustained investment in research and knowledge creation in driving innovation outcomes. In contrast, high-tech exports yield a smaller and statistically insignificant coefficient of 0.058 ($p = 0.118$), implying that export volume alone may not sufficiently reflect a nation’s internal innovation dynamics or absorptive capacity. The model explains approximately 11% of the within-group variation in GII scores ($R^2 = 0.110$), and the overall model is statistically significant ($F = 8.36$, $p < 0.001$), indicating that the included variables jointly influence innovation performance in a meaningful way. These findings support the conclusion that digital infrastructure and R&D investment are foundational to innovation-based development strategies among OECD countries.

Table 6. Final Regression Output

Variable	Coefficient	Standard Error	t-Statistic	p-Value
ICT Development Index (IDI)	0.412	0.078	5.28	0.000
R&D Expenditure (% of GDP)	0.287	0.091	3.15	0.002
High-Tech Exports (% of Total Exports)	0.058	0.037	1.57	0.118
Constant	1.842	0.231	7.97	0.000
Number of Observations	532			
R^2 (Within)	0.110			
F-Statistic (Model Significance)	8.36			0.000

Table 7 presents the country-specific fixed effect (intercept) estimates from the panel data regression model, with Türkiye used as the reference category (coefficient = 0.000). These intercepts capture unobserved, time-invariant factors that systematically affect countries' innovation performance beyond the explanatory variables in the model (digitalization, R&D, and high-tech exports). Countries such as Chile (4.19), Canada (4.06), and Sweden (3.40) exhibit the highest fixed effects, suggesting the presence of strong institutional frameworks, effective innovation ecosystems, or accumulated capabilities that consistently boost their innovation scores. In contrast, countries with negative fixed effects, including Colombia (-1.69), Costa Rica (-1.26), and Luxembourg (-1.08), may face structural challenges such as weaker governance, limited absorptive capacity, or inefficient R&D-commercialization channels, which inhibit innovation performance despite potential investments.

Table 7. Country-Specific Fixed Effects Coefficients

Country	Fixed Effect (Intercept)	Country	Fixed Effect (Intercept)
Chile	4.186561	Slovakia	1.340299
Canada	4.062202	Finland	1.186739
Sweden	3.398202	Austria	0.827592
Estonia	2.833337	Netherlands	0.625421
Hungary	2.644514	France	0.566118
Czech Republic	2.625232	Germany	0.308529
Slovenia	2.356002	Japan	0.133170
Lithuania	2.320100	Switzerland	0.071348
Latvia	2.104209	Belgium	0.012241
Ireland	1.910821	Türkiye	0.000000 (Reference)
Israel	1.736113	United States	-0.207236
Poland	1.720032	Italy	-0.264198
Iceland	1.658397	Denmark	-0.471292
Portugal	1.648812	Mexico	-0.686400
Norway	1.605713	Greece	-1.035687
New Zealand	1.407397	Spain	-1.039679
Korea	1.351682	Luxembourg	-1.078433
Australia	1.088301	Costa Rica	-1.264517
United Kingdom	1.010739	Colombia	-1.690905

Notably, Türkiye’s role as the reference group enables relative comparison; for instance, Germany (0.31) and Japan (0.13) perform only marginally better in baseline innovation terms once core explanatory variables are accounted for, while countries like the United States (-0.21) and Italy (-0.26) surprisingly fall below the baseline—potentially reflecting idiosyncratic national constraints or innovation model mismatches. These findings underscore the necessity of tailored national policies that address institutional quality, innovation culture, and systemic enablers—factors that standard inputs like digital infrastructure or R&D spending alone may not fully capture.

Figure 1 shows the histogram of residuals obtained from the fixed-effects panel regression. This plot provides an intuitive way to examine how the model’s error terms are distributed. The residuals appear roughly symmetric around zero and gradually thin out toward both tails, resembling a normal curve. Such a pattern indicates that neither strong skewness nor excess kurtosis is present — a desirable outcome that supports the assumptions required for standard inference in panel models. The smooth, bell-shaped form of the histogram further suggests that the residuals are approximately normally distributed, meaning the model specification is likely appropriate and the estimated coefficients can be regarded as stable and unbiased. Although formal tests of normality (such as Jarque-Bera or Shapiro-Wilk) could confirm this more rigorously, the visual pattern alone provides no evidence of serious departures from normality, reinforcing the credibility of the empirical results.

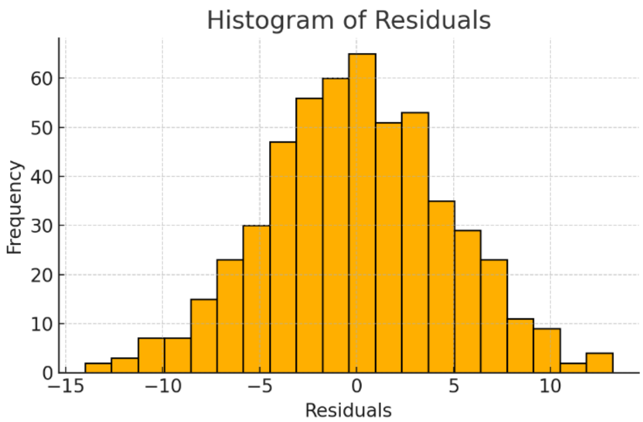

Figure 1. Histogram of Residuals

Figure 2 presents the Quantile–Quantile (Q–Q) plot of these residuals. This chart compares their empirical distribution with the theoretical quantiles of a standard normal distribution, offering another check on the validity of the normality assumption. The points largely fall along the 45-degree reference line, indicating that the residuals closely follow a normal distribution. Minor deviations at the tails are within acceptable limits and do not suggest a strong departure from normality. This visual evidence supports the assumption of normally distributed errors, which underpins the validity of hypothesis testing and confidence interval estimation in panel regression analysis. Together with the histogram of residuals (Figure 1), the Q–Q plot reinforces the conclusion that the model’s residuals meet the normality assumption, lending further credibility to the regression findings.

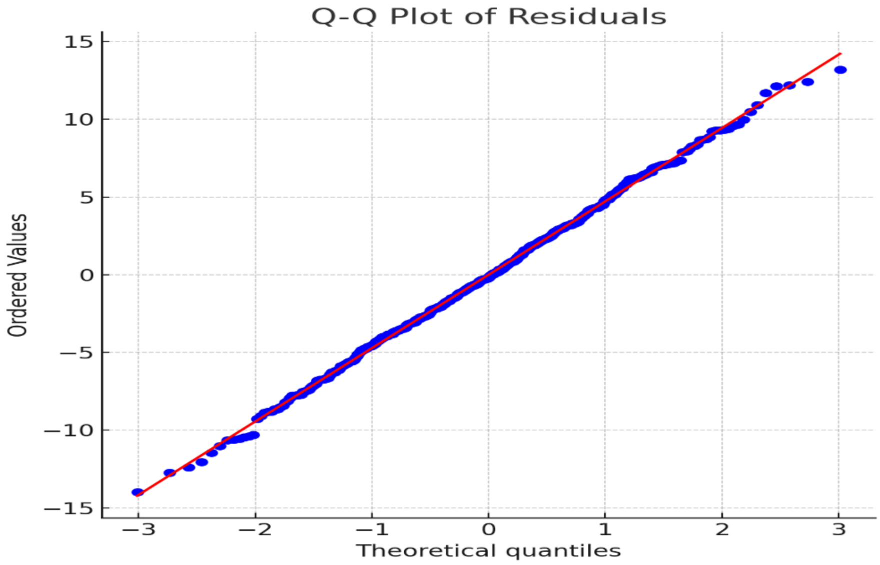

Figure 2. Q–Q Plot of Residuals

6. Discussion and Conclusion

This study investigated the drivers of national innovation performance across 38 OECD countries from 2010 to 2023 by employing a fixed effects panel data model. Focusing on digitalization (as measured by the, IDI), R&D expenditure, and high-tech exports, the findings reveal that digital infrastructure and R&D investment play a significant and robust role in enhancing a country's innovation capacity, whereas high-tech exports show a weaker and statistically insignificant relationship. These results contribute to the growing literature on the structural and policy determinants of innovation, with direct implications for sustainable development and strategic management at both national and organizational levels.

The significant and positive impact of digitalization on the GII scores confirms prior research that emphasizes the enabling role of ICT in fostering innovation ecosystems. Countries with advanced digital infrastructure can better leverage real-time information flows, collaborative platforms, and innovation networks to generate new knowledge and applications (Vu, 2011; Niebel, 2018). This finding also resonates with organizational perspectives that regard ICT not only as a technological enabler but also as a capability that enhances organizational learning and interconnectivity (Castellacci and Tveito, 2018). Similarly, the role of R&D expenditure aligns with classic innovation theory and the resource-based view, which identify internal investments in knowledge creation as critical to long-term competitiveness (Barney, 1991; Crespi and Zuniga, 2012). Countries that maintain consistent public and private R&D funding are better positioned to develop new technologies, attract high-skill labor, and embed innovation into their socio-economic fabric (OECD, 2020).

These findings can be interpreted through the theoretical perspectives adopted in this study. The significant role of R&D expenditure aligns with the RBV, as investments in knowledge creation act as rare and valuable resources for sustained competitiveness. The strong effect of digitalization resonates with the NIS perspective, emphasizing the institutional role of ICT infrastructure in facilitating knowledge flows. Furthermore, the complementary impact of digitalization and R&D supports the dynamic capabilities framework, which stresses the importance of reconfiguring resources to adapt to changing environments. Finally, the weak and heterogeneous role of high-tech exports confirms that innovation outcomes cannot be fully captured by trade performance alone, underscoring the systemic and contextual nature of innovation processes.

Beyond the statistical significance of the variables, the results offer important theoretical and policy implications. From a theoretical standpoint, the findings reinforce the relevance of dynamic capabilities, suggesting that countries with stronger adaptive capacities—reflected through the interplay of digitalization and R&D—are better positioned to sustain innovation-driven growth. This highlights the systemic nature of innovation, where institutional coordination, learning mechanisms, and absorptive capacity determine long-term competitiveness.

From a policy perspective, the results emphasize that digital transformation alone is insufficient to generate sustainable innovation unless supported by consistent R&D investment and institutional quality. Policymakers should therefore design integrated strategies that link digital infrastructure development with knowledge creation and diffusion mechanisms. In particular, for emerging economies such as Türkiye, aligning digital investments with human capital development and innovation governance reforms remains critical for enhancing national innovation performance.

Conversely, the insignificant relationship between high-tech exports and innovation performance suggests that output-based measures alone may not sufficiently capture a country's innovative capacity. While exports reflect market success, they may not indicate domestic absorptive capacity or the presence of systems that transform knowledge into scalable products and services (Cohen & Levinthal, 1990). This result supports the argument that innovation is as much about organizational routines, institutional context, and knowledge spillovers as it is about industrial output (Lundvall, 1992; Edquist, 2005).

It should also be noted that the GII as a dependent variable partly incorporates indicators related to ICT and R&D. Although the explanatory measures employed in this study are sourced independently, the possibility of partial construct overlap cannot be completely ruled out. This constitutes a methodological limitation that should be taken into account when interpreting the results. Nevertheless, the fixed-effects estimation helps mitigate some of the potential endogeneity concerns by controlling for unobserved heterogeneity across countries.

Türkiye's role as the reference category in the fixed effects model revealed structural insights. Many OECD countries—such as Chile, Canada, and Sweden—demonstrated significantly higher intercepts, suggesting more favorable systemic conditions for innovation. Türkiye's fixed effect of zero does not imply no effect, but rather serves as a baseline against which other countries' unobserved advantages or disadvantages are measured. This is consistent with the view that Türkiye is in a transitional innovation position—marked by fragmented innovation infrastructure, limited university-industry linkages, and relatively low R&D intensity compared to top OECD performers (Erkek and Karaata, 2020; World Bank, 2023).

From a sustainable development perspective, the study aligns closely with several of the United Nations SDGs. Specifically, the results support SDG 9 (Industry, Innovation and Infrastructure), SDG 8 (Decent Work and Economic Growth), and SDG 17 (Partnerships for the

Goals). IDI acts as a technological backbone for smart cities, e-governance, and clean production, while R&D investment is key to developing green technologies and resilient healthcare systems (Sachs et al., 2019). The findings thus reinforce the importance of innovation-oriented institutions and policies in achieving long-term sustainability outcomes.

From a managerial and organizational standpoint, the study underscores the need for alignment between NIS and organizational capabilities. The theory of dynamic capabilities suggests that countries and firms alike must develop the capacity to sense, seize, and transform opportunities in a rapidly changing environment (Teece et al., 1997). Governments should not only invest in ICT and R&D but also foster ecosystems that encourage entrepreneurial experimentation, inter-sectoral collaboration, and knowledge diffusion—especially among SMEs and regional clusters (Zahra and George, 2002). For countries like Türkiye, this means moving beyond infrastructure expansion to also address governance, institutional trust, and skill development—factors that influence how innovations are generated, adopted, and diffused.

The originality of this study lies not only in the scope of its dataset and methodological rigor but also in its theoretical and policy contributions. By combining digitalization, R&D intensity, and high-technology exports within a unified empirical model, the study demonstrates how these drivers interact differently across OECD countries over time. Importantly, the finding that high-technology exports do not have a significant impact challenges conventional assumptions and highlights the need to revisit how innovation outputs are measured. Moreover, the integration of RBV, NIS, and dynamic capabilities perspectives provides a richer theoretical lens than previous works. By embedding the results within the sustainability agenda, this study contributes novel insights into how digital infrastructure and knowledge investments can be mobilized to design inclusive and resilient innovation strategies.

While the model accounts for some of the core determinants of innovation, it explains only 11% of the variation in GII scores, suggesting that other critical factors—such as human capital, rule of law, or innovation culture—may further enrich the analysis. Moreover, disaggregating high-tech exports by industry or adding interaction terms (e.g., between R&D and IDI) could uncover deeper synergies. Future research might also adopt a mixed-method approach to better understand how organizational dynamics mediate national innovation outcomes.

Despite its contributions, this study is not without limitations. The modest explanatory power of the model ($R^2 = 0.11$) indicates that innovation performance is influenced by additional structural, institutional, and cultural factors not captured in the current framework—such as human capital quality, regulatory efficiency, and innovation culture. Future research could expand the model by incorporating these dimensions or by decomposing the GII into sub-indices that allow for a more granular analysis. Moreover, advanced econometric approaches such as instrumental variable (IV) estimation or dynamic panel methods could be employed to further address potential endogeneity and explore causal linkages.

Morover, this study highlights that national innovation performance in OECD countries is significantly driven by digital infrastructure and R&D investment, while the role of high-tech exports is less definitive. For emerging economies like Türkiye, the findings point to the urgency of building not only physical and financial inputs but also institutional and organizational capacities that support innovation. These efforts are essential not just for economic competitiveness but also for delivering the sustainable development agenda in a world increasingly shaped by digital and knowledge-based transformations.

Another potential limitation of this research concerns the dependent variable. Since the GII already incorporates ICT and R&D elements, there is a risk of partial construct overlap and possible endogeneity. While this risk has been mitigated by using independent data sources and a fixed-effects model, future studies could employ instrumental variable (IV) or two-stage least squares (2SLS) methods to further address endogeneity concerns.

7. Policy Recommendations

Based on the findings of this study, several policy implications emerge that are crucial for enhancing national innovation performance in the context of sustainable development and organizational resilience. First and foremost, governments—particularly in emerging economies such as Türkiye—should prioritize long-term investments in digital infrastructure as a foundational enabler of innovation. This includes expanding broadband coverage, ensuring affordable access to ICT, and integrating digital tools into public service delivery and education systems. Such efforts not only support innovation ecosystems but also directly contribute to achieving SDG 9 (Industry, Innovation and Infrastructure) and SDG 4 (Quality Education).

R&D spending should be recognized not as a financial burden but as a long-term investment in national competitiveness. Governments can promote this by encouraging public–private partnerships through shared funding mechanisms, tax incentives, and programs that directly support collaboration between universities and industry. Since research investment has a well-documented influence on innovation performance, national strategies need to set out clear targets for raising R&D intensity—especially in knowledge-driven sectors such as clean energy, biotechnology, and artificial intelligence.

The limited and statistically insignificant effect of high-technology exports found in this study points to another challenge: the need to improve domestic absorptive capacity. Policies that strengthen workforce skills, managerial capabilities, and institutional coordination can help address this gap. Practical measures—such as expanding innovation hubs, supporting start-ups through incubators, and improving vocational training for SMEs—can ensure that technological production translates into economy-wide innovation gains.

Innovation policy should also be framed in a broader, system-wide context. The quality of institutions, the efficiency of regulations, and the degree of public trust in governance all play crucial roles in enabling innovation to spread. In Türkiye's case, reducing fragmentation within the national innovation ecosystem, improving data management, and creating transparent and predictable institutional frameworks will be essential steps toward more transformative and sustainable innovation outcomes.

Finally, innovation strategies must align with wider sustainability goals. Integrating climate-smart technologies, fostering inclusive innovation practices, and placing social value creation at the center of policy design will ensure that innovation supports not only economic growth but also equitable, resilient, and environmentally responsible futures in an increasingly digital world.

Declaration of Research and Publication Ethics
This study which does not require ethics committee approval and/or legal/specific permission complies with the research and publication ethics.

Researcher's Contribution Rate Statement
I am a single author of this paper. My contribution is 100%.

Declaration of Researcher's Conflict of Interest
There is no potential conflicts of interest in this study.

References

Barney, J. (1991). Firm resources and sustained competitive advantage. *Journal of Management*, 17(1), 99–120. https://doi.org/10.1177/014920639101700108

Castellacci, F. and Natera, J.M. (2013). The dynamics of national innovation systems: A panel cointegration analysis of the coevolution between innovative capability and absorptive capacity. *Research Policy*, 42(3), 579–594. https://doi.org/10.1016/j.respol.2012.10.006

Castellacci, F. and Tveito, V. (2018). Innovation and the ICT–productivity link: Evidence from OECD industries. *Research Policy*, 47(9), 1611–1630. https://doi.org/10.1016/j.respol.2018.05.014

Cirera, X. and Maloney, W.F. (2017). *The innovation paradox: Developing-country capabilities and the unrealized promise of technological catch-up*. https://doi.org/10.1596/978-1-4648-1160-9

Cohen, W.M. and Levinthal, D.A. (1990). Absorptive capacity: A new perspective on learning and innovation. *Administrative Science Quarterly*, 35(1), 128–152. https://doi.org/10.2307/2393553

Crespi, G. and Zuniga, P. (2012). Innovation and productivity: Evidence from six Latin American countries. *World Development*, 40(2), 273–290. https://doi.org/10.1016/j.worlddev.2011.07.010

Edquist, C. (2005). *Systems of innovation: Perspectives and challenges.* In J. Fagerberg, D.C. Mowery and R.R. Nelson (Eds.), *The Oxford handbook of innovation* (pp. 181–208). Oxford: Oxford University Press.

Erkek, E. and Karaata, S.O. (2020). Türkiye’de yenilikçilik ve girişimcilik kapasitesinin değerlendirilmesi. *İktisat ve Toplum*, 10(113), 56–63. Retrieved from https://iktisatvetoplum.com/

Filippetti, A. and Archibugi, D. (2011). Innovation in times of crisis: National systems of innovation, structure, and demand. *Research Policy*, 40(2), 179–192. https://doi.org/10.1016/j.respol.2010.09.001

Gujarati, D.N. and Porter, D.C. (2009). Basic econometrics (5th ed.). McGraw-Hill Education.

Lee, C. and Xia, Y. (2018). The synergy between information and communication technology and R&D as a platform for innovation: Evidence from Asia and the Pacific. *Technological Forecasting and Social Change*, 137, 56–62. https://doi.org/10.1016/j.techfore.2018.07.016

Lee, H., Kim, Y.J. and Park, Y. (2021). ICT infrastructure, innovation capability and firm performance: Evidence from OECD countries. *Technology Analysis & Strategic Management*, 33(3), 268–281. https://doi.org/10.1080/09537325.2020.1810759

Lundvall, B.-Å. (1992). *National systems of innovation: Towards a theory of innovation and interactive learning.* UK: Pinter Publishers.

Maddala, G.S. and Wu, S. (1999). A comparative study of unit root tests with panel data and a new simple test. *Oxford Bulletin of Economics and Statistics*, 61(S1), 631–652. https://doi.org/10.1111/1468-0084.0610s1631

Niebel, T. (2018). ICT and economic growth – Comparing developing, emerging and developed countries. *World Development*, 104, 197–211. https://doi.org/10.1016/j.worlddev.2017.11.024

OECD. (2020). *OECD science, technology and innovation outlook 2020: Are changing lives for the better?* https://doi.org/10.1787/1110c1c2-en

Sachs, J.D., Schmidt-Traub, G., Kroll, C., Lafortune, G. and Fuller, G. (2019). *Sustainable development report 2019.* (*Bertelsmann Stiftung and Sustainable Development Solutions Network (SDSN)).* Retrieved from https://sdgindex.org/reports/sustainable-development-report-2019/

Teece, D.J., Pisano, G. and Shuen, A. (1997). Dynamic capabilities and strategic management. *Strategic Management Journal*, 18(7), 509–533. https://doi.org/10.1002/(SICI)1097-0266(199708)18:7<509::AID-SMJ882>3.0.CO;2-Z

Vu, K.M. (2011). ICT as a source of economic growth in the information age: Empirical evidence from the 1996–2005 period. *Telecommunications Policy*, 35(4), 357–372. https://doi.org/10.1016/j.telpol.2011.01.002

Wooldridge, J.M. (2010). *Econometric analysis of cross section and panel data* (2nd ed.). USA: MIT Press.

World Bank. (2023). *Turkey country economic memorandum: Innovation and competitiveness in a changing world.* Retrieved from https://documents.worldbank.org/en/publication/documents-reports/documentdetail

Zahra, S.A. and George, G. (2002). Absorptive capacity: A review, reconceptualization, and extension. *Academy of Management Review*, 27(2), 185–203. https://doi.org/10.5465/amr.2002.6587995