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Sustainable Competitiveness under Conflict: Innovation Patterns and Environmental Pressures in Ukraine

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Abstract: Ukrainian enterprises face significant challenges in leveraging innovation for competitiveness and sustainable development amidst post-war reconstruction and global market integration, with limited empirical evidence guiding effective strategies. This study examined the impact of innovative activity on companies' competitiveness and its contribution to sustainable development within Ukraine's national economy from 2018 to 2024. Utilizing a quantitative data analysis of 612 enterprises across key sectors such as information technology (IT), manufacturing, and agriculture, the research employed fixed-effects regression models on longitudinal data from Ukraine's State Statistics Service. Key metrics included Research and Development (R&D) Intensity, Patent Activity, Process Innovation Adoption, alongside competitiveness indicators (Export/Revenue Growth and Market Share), as well as sustainability indicators (Job Creation, Energy Efficiency, and Greenhouse Gas (GHG) Emissions). Results demonstrated that a 1% increase in R&D Intensity drove 2.71% higher Export Growth ($p < 0.001$), while Process Innovation boosted Revenue by 4.38% per implementation level ($p < 0.01$) and reduced GHG Emissions by 12.7% ($p < 0.001$). A critical R&D Intensity threshold of 3.5% triggered exponential returns in competitiveness. Sectoral analysis revealed superior innovation resilience of IT (78% wartime retention vs. 42% in manufacturing) and reliance on Non-R&D Innovation for Job Creation in agriculture. The findings necessitate tiered R&D tax incentives for enterprises that exceed the 3.5% intensity benchmark, as well as the establishment of sector-specific innovation hubs. Policymakers should prioritize sustainability-linked financing and wartime adaptation funds targeting regions with more than 15% infrastructural damage. This study provided the first quantitative evidence linking types of innovation to dual competitiveness and sustainability outcomes in conflict-affected Ukraine, hence offering actionable pathways for economic recovery.

Keywords: Innovation; Firm competitiveness; Sustainable development; Innovation activity; National economy; Wartime economy

1. Introduction

In the contemporary global economy, innovation is widely recognized as a fundamental driver of enterprises' competitiveness and national sustainable development (Mu et al., 2025). Firms that leverage novel technologies, processes, and business models gain significant advantages in terms of efficiency, market positioning, and adaptability (Hokmabadi et al., 2024). Innovation is critical for achieving Sustainable Development Goals (SDGs)

(Syhyda et al., 2023) and facilitates resource efficiency. It reduces environmental footprints and fosters inclusive economic growth (Bobkova et al., 2020). In Ukraine, these mechanisms help firms cope with shocks and rebuild capacity.

Ukraine faces profound economic challenges, including the immense task of post-war reconstruction, the need to modernize critical infrastructure, and deeper integration into competitive global markets (Dyak, 2023). Overcoming these challenges and achieving long-term economic resilience require a strategic shift toward innovation-driven growth. For Ukraine, harnessing the innovative potential of its enterprises is not merely an economic strategy but a vital imperative (Zhyvko et al., 2024). It supports national recovery, enhances global competitiveness, and drives sustainable socio-economic progress. These pressures render innovation theories especially relevant to Ukraine's disrupted markets.

Although innovation is widely recognized as a key driver of competitiveness and sustainable development, its effects in the Ukrainian context remain poorly understood (Kuzior et al., 2022). Most existing studies, such as those by Sayari et al. (2025) and Syhyda et al. (2023), focused on developed economies or examined innovation, competitiveness, and sustainability in isolation. Ukraine's enterprises face unique challenges such as war-related disruptions, damaged infrastructure, limited financing, and regulatory uncertainty (Grum & Kobal Grum, 2023; Vakulenko et al., 2025). These conditions make innovation not only optional but also essential.

The relationship among innovation, competitiveness, and sustainable development is grounded in several foundational economic and management theories. Schumpeter (2013)'s theory of creative destruction posits that innovation drives economic progress by disrupting established markets and creating new industries, thereby fundamentally reshaping competitive landscapes. This process is essential for long-term economic dynamism. Porter's diamond model and theory of competitive advantage emphasize that firms achieve sustainable competitive advantages through strategic innovation, thus enabling superior value creation through differentiation or cost leadership (Ketels, 2024). The Resource-Based View (RBV), articulated by Barney (1991), further explained competitiveness and asserted that firms gained advantage through valuable, rare, inimitable, and non-substitutable (VRIN) resources and capabilities, with innovation capability being paramount. These frameworks were critically extended in this study to analyze how innovation functioned as a strategic resource for firms operating within a severe exogenous shock such as war.

One of the most important factors that leads to national competitiveness and sustainable development is innovation (Kashchena et al., 2023). The concept of creative destruction, developed by Schumpeter, demonstrated the role of new products, processes, and organizational forms in driving economic growth (Schumpeter, 1983). The next research focused on developing and enhancing firms' capabilities. Dynamic capabilities present how companies reorganize resources to remain competitive within dynamic environments (Teece, 2007). These conditions also encourage innovation due to effective technology policy and assessment (Funaba, 1988).

The process of innovation has been made more collaborative. The open innovation model by Chesbrough emphasizes the integration of both internal and external ideas in order to promote technologies (Chesbrough, 2012). The Triple Helix model demonstrates that the collaboration among the universities, industry, and government increases the rate of innovation and economic growth (Leydesdorff & Etzkowitz, 1998). Sustainable development theory is gradually framed by Elkington & Rowlands (1999)'s Triple Bottom Line (TBL) model, which requires enterprises to balance economic prosperity, environmental stewardship, and social equity. This aligns with the broader United Nations (UN) SDGs framework, which provides specific targets for national and corporate contributions to global sustainability. Contemporary digital innovation theory highlights how digital technologies act as catalysts for both novel business models and sustainable solutions (George et al., 2021). These theoretical foundations demonstrate how innovation links enterprise capabilities with national competitiveness in both stable and transitional contexts (Yermachenko et al., 2023). These theories collectively establish that innovation is not merely a driver of firm-level performance but a critical mechanism for achieving resilient competitiveness and aligning economic growth with environmental and social imperatives.

Empirical research consistently underscored the positive relationship between innovation investment and firms' competitiveness across diverse economies. Bloom et al. (2019) provided compelling evidence with the use of global firm-level data and showed that companies with higher spending on Research and Development (R&D) and patent output significantly outperformed peers in the growth of productivity and profitability over the long term. Furthermore, studies increasingly linked innovation to sustainability outcomes. Sarfraz et al. (2022) investigated the impact of innovation capabilities and green process innovation on the sustainable performance of manufacturing firms in Pakistan. Utilizing data from 299 employees and applying structural equation modeling via SmartPLS, the study found a significantly positive relationship between innovation activities and sustainability outcomes. The authors further demonstrated that green product innovation mediated these effects. At the same time, digital leadership served as a critical moderating factor, to enhance the impact of innovation on employee creativity and firm-level sustainability. George et al. (2021) and Kravchenko et al. (2024) investigated the role of digital technologies in addressing climate change and advancing sustainable development. The study highlighted how entrepreneurial organizations employed digital tools to initiate innovative solutions for complex societal issues, conceptualized as digital sustainability activities. It proposed a forward-looking research agenda on business models, ecosystems, and institutional trust, in order to position digital sustainability as a catalyst for advancing empirical research in entrepreneurship and innovation with meaningful societal outcomes. Zhang & Leng (2025) empirically examined the link between green innovation and corporate social responsibility within Chinese enterprises. The study found a strongly positive association between the two, particularly in economically advanced regions. It further showed that corporate performance mediated this relationship, hence suggesting that firms implementing green innovation were more likely to fulfil corporate social responsibility commitments. Recent work in transition economies (e.g., Berg et al., 2024) has also reaffirmed that innovation systems in post-socialist settings require distinct analytical treatment, in order to strengthen the relevance of examining Ukraine.

However, a critical evaluation revealed that much of this global literature originated from stable and developed economies with mature innovation ecosystems. The transferability of findings, in particular the specific mechanisms linking innovation to competitiveness and sustainability, to economies undergoing significant disruption or transition like Ukraine, may be limited. Studies also often focused on large corporations, potentially neglecting the dynamics within small and medium enterprises (SMEs), which form the backbone of many economies including Ukraine. Evidence from post-conflict environments (Alayasa & Nemec, 2025) showed that innovation often behaved differently under instability, thus highlighting the need for context-specific empirical inquiry.

Research on innovation within Ukraine has intensified, particularly since 2022; this reflects the heightened urgency of economic recovery and resilience. Ilyina (2025) identified persistent structural barriers hindering innovation in Ukrainian enterprises, including chronic underfunding of R&D, limited access to venture capital, bureaucratic hurdles, and a historical reliance on outdated technologies, particularly in traditional sectors like heavy industry and agriculture.

Shpak et al. (2020) investigated the transition of Ukraine toward a circular economy by examining the disconnection between current resource management practices and long-term sustainability goals. Drawing on their experience with the EU, they assessed waste management trends using key performance indicators and conducted a content analysis to evaluate national conditions. The authors proposed a conceptual framework to guide managerial decision making for circular business models. They developed a multifactor model, refining the Farrar–Glauber method, to quantify the influence of environmental and economic variables on the phenomenon. Their findings suggested that reducing waste intensity per unit of gross domestic product (GDP) by 1 kg/$1000 could lead to a decrease of approximately 952.7 million tonnes in waste from economic activities, thus underlining the importance of targeted environmental investments in shaping sustainable outcomes.

Odrekhivskyi et al. (2025) developed a comprehensive approach for assessing and forecasting the environmental sustainability of innovative enterprises, in order to support their long-term development. The study introduced a management mechanism that incorporated intelligent monitoring systems and indicator-based evaluations, utilizing expert scoring and predictive modelling via Markov chains. Having applied to Enzym Company in Ukraine (2017–2021), the methodology enabled an objective assessment of sustainability status and informed the strategic adoption of eco-innovations. Dobrovolska et al. (2023) and Sumets et al. (2022) further demonstrated how organic farming models exemplified organizational innovations that advanced sustainability goals within Ukraine's agricultural sector.

According to recent research, innovation performance is quite diverse across national contexts. As noticed by Brzyska (2023), Poland has low innovativeness, but with time, it has been slowly improving with human capital and trademark protection, while continuing to be weak in terms of investment and business-research collaboration. In a review of the ROInnovate in Romania, the World Bank (2024) identified best practices in international innovation agencies, including sequencing, governance, and the integration of climate-related priorities. The Western Balkans evidence showed that innovation was a strong factor in the growth of the green economy. Plakaj Vërbovci et al. (2024) discovered that innovation, R&D, patents, and favorable business conditions had a positively and statistically significant effect on the green economy, as innovation had a significantly positive and significant coefficient ($B = 0.41$). The 2022/2023 national R&D survey of Rwanda also recorded an upward trend in the spending on R&D, greater research output, and a disproportionate involvement of the business sector, thus highlighting the requisite to invest specifically, develop stronger business-focused collaborations, and invest more in human resources (National Council for Science & Technology, 2024).

The studies of startup ecosystems contribute more to the understanding of innovation systems. Vonoga & Klavina (2022) demonstrated that the Baltic startup associations differed greatly in scale and form, as in Latvia there were much fewer startups than in Lithuania and Estonia, given the differences in the institutional system and ecosystem. In these studies, the overall result was the support of the idea that the national innovation capacity was subject to the coordinated policy design, the long-term and permanent funding of R&D, the institutional support mechanism, and the connectivity of the ecosystem, which determine competitiveness, sustainability, and long-term economic development. Much of the existing literature is qualitative (case studies and expert interviews) or descriptive (statistical overviews) (AlQhtani, 2025; Orazbayev et al., 2017). While valuable for identifying challenges and trends, these studies often lack the methodological rigor to establish causal links between specific innovation activities and measurable outcomes in competitiveness (e.g., market share growth, export expansion, etc.) or crucially, sustainable development (e.g., quantified environmental benefits, social inclusion metrics, etc.). There is a pronounced scarcity of large-scale quantitative studies within Ukraine that simultaneously model the impact of innovation on both competitiveness and multi-dimensional sustainability indicators.

The preceding review illuminated a critical void in the current body of knowledge. While global studies established broad links among innovation, competitiveness, and sustainability, Ukrainian research identified context-specific challenges and sectoral potentials. There is a conspicuous absence of rigorously and quantitatively empirical research within Ukraine that systematically investigates and quantifies the interrelationships among these three constructs.

This gap hinders the ability of Ukrainian enterprises to make evidence-based investment decisions in innovation. It constrains policymakers in designing effective and targeted interventions to foster innovation-driven and sustainable recovery and growth (Yemets et al., 2025). This study addressed these gaps by exploring how innovation supported enterprise resilience and national recovery in Ukraine's current economic environment. To enhance conceptual clarity, this study also formulated explicit hypotheses:

H1: Innovative activity positively influences enterprises' competitiveness;

H2: Drivers of innovation strengthen enterprises' innovation capacity, while barriers weaken it;

H3: Enterprise innovation contributes positively to national sustainable development.

This study aims to investigate how the innovative activities of Ukrainian enterprises influence their competitiveness and contribute to the sustainable development of the national economy. The following specific questions guide the research:

RQ1. How does innovative activity affect the competitiveness of Ukrainian enterprises?

RQ2. What are the key factors driving or hindering innovative activity in Ukrainian enterprises?

RQ3. To what extent does the innovative activity of enterprises contribute to the sustainable development of Ukraine's national economy?

The findings of this research hold substantial practical value. Ukrainian enterprises could utilize these insights to refine their innovation strategies, optimize resource allocation, and enhance their competitive positioning both domestically and internationally.

Policymakers will gain evidence-based guidance for designing targeted interventions, such as supportive regulatory frameworks, financial incentives, and infrastructure development, to effectively stimulate and sustain enterprises' innovation. Ultimately, fostering a more innovative enterprise sector is expected to significantly contribute to national economic recovery, resilience, and sustainable growth trajectory in Ukraine, and its successful integration into the global economy.

This study focused specifically on Ukrainian enterprises operating within key sectors pivotal to the national economy and recovery efforts: Information Technology (IT), Manufacturing, and Agriculture. The analysis primarily utilized data spanning the period from 2018 to 2024, to capture both pre-war conditions and critical phases of wartime adaptation and early recovery, thereby providing a relevant contemporary perspective on innovation dynamics.

2. Methodology

This study employed a quantitative and non-experimental research design focused on establishing analytical relationships between variables (Duckett, 2021). Specifically, it adopted a causal-comparative approach using longitudinal panel data. The primary objective is to identify and quantify the relationships between enterprises' innovative activity and the outcomes of competitiveness and sustainable development within the defined Ukrainian context. A mixed administrative-survey data structure underpinned this design to clarify the transparency of sources, based on the following steps:

(1) Employ robust quantitative methods (e.g., multivariate regression analysis) to isolate the causal effect of specific innovation indicators (e.g., R&D spending, patent applications, introduction of new products, etc.) on concrete measures of enterprises' competitiveness (e.g., revenue growth, export intensity, market share, etc.) in the unique Ukrainian context;

(2) Quantify the contribution of enterprises' innovation activities to key dimensions of sustainable development, including environmental performance, social outcomes (such as job quality and creation), and economic resilience, at both the firm and aggregate national levels within Ukraine; and

(3) Integrate competitiveness and sustainability outcomes into a unified analytical framework to understand potential synergies or trade-offs arising from innovation activities in a post-conflict and developing economy setting.

This design was chosen for its ability to analyze existing data over a long period to infer potential causal links, hence acknowledging the inherent limitations in establishing definitive causality without experimental manipulation. The analysis primarily leveraged secondary data, supplemented by primary data collection where feasible, to provide a comprehensive empirical assessment aligned with the research aim and questions. This dual-source strategy also addressed earlier concerns about unclear data provenance.

In Figure 1, the theoretical framework is a visual representation of the pathway of the theoretical narrative of innovation inputs to national outcomes. It has placed the RBV by Barney as the framework theory, as it provides sufficient justification of R&D and patents as strategic resources, which facilitate Schumpeterian creative destruction. This innovation, in turn, both pushes the competitive advantage of Porter (determined by the market share and exports) and is determined by the dynamic capabilities and open cooperation. In the end, these interrelated processes are assessed alongside the TBL presented by Elkington and the UN SDGs. The final results comprise national economic resilience and sustainable development.

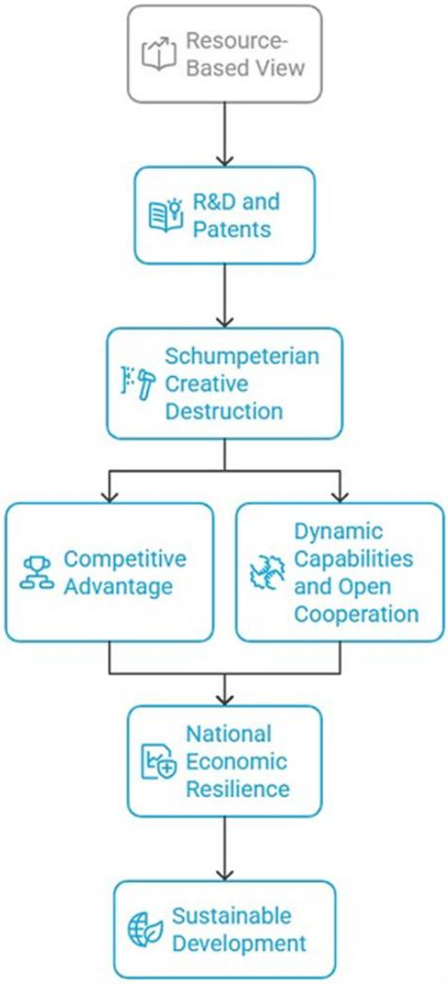

Figure 1. Conceptual framework

2.1 Data Sources

The acquisition of data utilized a multi-source strategy to ensure robustness and triangulation (Khan et al., 2025). The cornerstone of the analysis was officially statistical data from the State Statistics Service of Ukraine (Derzhstat, https://stat.gov.ua/en). This microdata included a longitudinal panel of administrative data (2018–2024) that was used to make thorough causal inferences, as the data covered the full population of the target sectors. Key datasets included annual statistical bulletins on "Scientific and Innovative Activity in Ukraine" covering the year 2018 to 2024. Enterprise-level data were drawn from statistical forms, such as Form 1-innovation (Report on Innovative Activity of the Enterprise) and Form 2-science (Report on Performing Scientific Research and Development), accessed via Derzhstat's microdata portal under appropriate research agreements that ensured confidentiality. These forms provided detailed information on R&D expenditures, types of innovation, innovation expenditures, sources of funding, personnel engaged in R&D and innovation, and output like patents and new products. This clarified that administrative microdata formed the backbone of the panel.

Complementary economic performance data, including revenue, exports, and employment, were gathered from Derzhstat's business register and structural business statistics (e.g., Form 1-enterprise, Annual Report of the Enterprise). Sector-specific reports were consulted from relevant Ukrainian ministries, including the Ministry of Digital Transformation for the IT sector, the Ministry of Agrarian Policy and Food for Agriculture, and the Ministry of Economy, Environment, and Agriculture of Ukraine. Macroeconomic indicators, including the growth of GDP, inflation, and exchange rates, were sourced from the National Bank of Ukraine and Derzhstat. In addition, contextual international benchmarking data were utilized from the Main Science and Technology Indicators (MSTI) database of the Organization for Economic Cooperation and Development (OECD) and the World Development Indicators (WDI) of the World Bank.

The qualitative variables to be captured by granular variables required a primary cross-sectional survey in 2024. The survey focused on the same group of firms and included perceptual data about drivers, barriers, and more subtle sustainability indicators that were not available in administrative data. To address potential gaps in secondary data granularity, particularly regarding nuanced drivers, barriers, and specific sustainability metrics, a supplementary cross-sectional survey of Ukrainian enterprises was conducted (Mahooti et al., 2025). The instrument of the survey was developed based on established frameworks, such as the Community Innovation Survey (CIS), and tailored to the Ukrainian context and research variables (Diachenko et al., 2022). It measured specific types and intensities of innovative activities beyond basic R&D spending, as well as perceived drivers such as availability of skilled labour, access to the European Union (EU) markets, and collaboration networks whereas barriers included financing constraints, regulatory uncertainty, and war-related disruptions. The survey also assessed detailed metrics of competitiveness, such as perceived changes in market position and specific export market dynamics, and gathered data on specific sustainability practices and outcomes, including details of energy consumption, waste reduction initiatives, social investment programs, and measures for employee well-being. This combined structure directly responds to the request for clearer sampling and origin of data. The survey formed one cross-section sample in 2024 with enterprises being the unit of the study. The procedures of sampling, the definition of variables, and the blocks of questions can be fully replicated as they are based on CIS requirements.

The deployment of the survey employed a mixed-mode approach, combining an online platform and telephone interviews, to target key informants such as Chief Executive Officers, Innovation Managers, and Chief Financial Officers within the sampling frame (White & Bessette, 2025). Participation was voluntary and anonymous. The mode provided extensive coverage and repeatability as the sampling frame, role of respondents and contact procedures were recorded.

2.2 Sample

The study population encompassed Ukrainian enterprises operating within three strategically critical sectors: IT (under 'statistical classification of economic activities' in the European Community, abbreviated as NACE, codes K62-K63), Manufacturing (NACE C10-C33), and Agriculture (NACE A01-A03), covering the period from 2018 to 2024. In order to define replicability, the entire population was composed of 3,672 enterprises (428 IT, 2,311 Manufacturing, and 933 Agriculture), and all the sampling stages were sampled. The final analytical sample was constructed using stratified random sampling to ensure robust representation across key dimensions. Enterprises were first categorized into their respective sectors using verified NACE Revision 2 codes from Ukraine's official business register. The proportions of the population to the sectoral sampling were proportional to the shares in the population, which led to 72 IT, 384 Manufacturing, and 156 Agriculture enterprises in the final 612-enterprise panel. Stratification further accounted for firm size by dividing enterprises into four categories: micro-firms (<10 employees), small (10–49 employees), medium (50–249 employees), and large enterprises (≥250 employees) to capture differences in innovation capacity across organizational scales (Petrunenko et al., 2021). This created a size-based organization consisting of 118 micro, 233 small, 181 medium, and 80 large enterprises, which were based on national distributions of firm size, in order to clarify how sampling aligns with the administrative base.

Where historical data permitted, an additional stratification layer was applied based on innovation intensity (Castrillo et al., 2024). This distinguished a firm's reporting of innovation activities during at least one year within the 2018-2021 pre-war period from non-innovators, thus enabling a comparative analysis of innovation trajectories. The results of this process were 276 innovators and 336 non-innovators; this was proportional to the categories of sector and size. Data extraction occurred annually across the seven-year timeframe, resulting in an unbalanced panel structure. To maintain analytical rigor and mitigate attrition bias, only enterprises with at least three consecutive years of complete data were retained in the final sample (Nasir & Zhang, 2024). The transparency of the missing data was also guaranteed on the basis of this rule. The companies that had more than 5% of missing data were not included whereas minor missing values were filled in with sector-specific means. Interquartile thresholds were used to determine outliers and the 1st and 99th percentiles were used to winsorize outliers. This approach ensured coverage of three distinct economic phases: pre-war operations (2018–2021), the immediate invasion shock (2022), and early adaptation/recovery (2023–2024).

The final sample consisted of 612 enterprises, proportionally distributed across the categories of sector and size to reflect their representation in Ukraine's national economy. This sample size was determined to provide sufficient statistical power for the planned multivariate regression analyses. The requirement of adequacy was checked with the minimum-sample rule of multivariate models and consequently, ensured that the 612-unit sample was enough. The sampling frame was derived from the State Statistics Service of Ukraine (Derzhstat) business register, with verification against tax administration records to confirm operational status. For the supplementary survey component, a randomized subset of 176 enterprises was drawn from this master sample frame to collect primary data on innovation drivers and sustainability metrics. There was also proportionality in the survey selection based on all the previous stratification layers, whereby sector, size, and innovation-intensity distributions in the 176-unit subset were equal to the 612-unit administrative panel without any reclassification across the sources of data.

2.3 Variables and Measurement

Variables were operationalized based on theoretical foundations, literature review, and data availability within the Ukrainian context. All financial variables were adjusted for inflation using the Ukrainian Consumer Price Index (CPI). The independent variable, Innovative Activity (IA), was measured by multiple indicators. R&D Intensity (IA1) was calculated as annual enterprise R&D expenditure divided by annual operating revenue, using data from Derzhstat Form 2-science and the enterprise survey. Product Innovation Output (IA2) reflected the number of new or significantly improved products or services launched in the reporting year, sourced from Form 1-innovation and the survey. Process Innovation Adoption (IA3) was captured either as a binary variable or on an ordinal scale, indicating the extent of new or improved processes based on Form 1-innovation and the survey. Patent Activity (IA4) represented the annual count of patent applications filed by the enterprise, obtained from innovation bulletins, the Ukrainian Initial Public Offering (IPO) database, and the survey. Non-R&D Innovation Expenditure (IA5) included spending on innovation-related machinery, software, training, marketing, and external knowledge, expressed as a percentage of the revenue, with data from Form 1-innovation and the survey.

Dependent variables were split into two categories: Competitiveness (COMP) and Sustainable Development Contribution (SDC). Competitiveness was assessed through Export Growth (COMP1), which measures the annual percentage change in export value in constant currency, using data from customs and enterprise reports. Revenue Growth (COMP2) tracked changes in operating revenue, using Form 1-enterprise. Market Share (COMP3) was computed as the enterprise's share of total sectoral revenue. Labor Productivity (COMP4) was measured by value added per employee (Dykha et al., 2024). SDC indicators spanned economic, environmental, and social dimensions. Job Creation (SDC_Eco1) referred to the net changes in full time employment or its equivalent. Energy Efficiency (SDC_Env1) was calculated as energy consumption per unit of output or revenue. Greenhouse Gas (GHG) Intensity (SDC_Env2) represented estimated CO2e emissions per unit of output or revenue, based on responses to the survey and emission factors. Employee Training Investment (SDC_Soc1) indicated training expenditure as a percentage of payroll. Health & Safety Performance (SDC_Soc2) was measured through workplace accidents per 100 employees or lost time injury frequency rate (LTIFR), using survey and labor inspection reports.

Control variables included Firm Size (CTRL1), measured as the natural logarithm of total assets or employee count, based on Derzhstat data. Industry Sector (CTRL2) was controlled using NACE code dummies for IT, Manufacturing, and Agriculture. Firm Age (CTRL3) was measured by the number of years since establishment. The Debt-to-Equity ratio and a binary indicator for recent bank loans or grants measured access to Finance (CTRL4). Foreign Ownership (CTRL5) was a binary or percentage-based indicator. Macroeconomic Conditions (CTRL6) included national GDP growth and inflation, drawn from the National Bank of Ukraine (NBU) and Derzhstat. Wartime Impact (CTRL7) was captured through year dummies for 2022–2024 and regional dummies reflecting proximity to conflict zones, with the use of Derzhstat and conflict map data. This set aligns with standard panel-data controls for mitigating omitted-variable bias.

2.4 Quantitative Methods

Data analysis proceeded in a structured sequence (Bexell et al., 2025). The preparation of data involved multiple imputation for handling missing values, Winsorization for outlier treatment, log transformation for variables with skewed distributions, and restructuring of the data into a balanced panel dataset (Woods et al., 2024). Descriptive statistics including means, medians, standard deviations, and ranges were computed. Bivariate relationships among key variables were assessed using Pearson or Spearman correlations, depending on normality. Correlation matrices also helped detect multicollinearity before regression. The main analysis used panel data regression to test causal effects, guided by the following general model (Arraya & Ferreira, 2025; Maziliauske, 2024; Yuan & Li, 2024; Zhang & Lim, 2025):

$$Y_{it} = \beta_o + \beta_1 IA_{it} + \sum \beta_k Controls_{kit} + \alpha_i + \lambda_t + \varepsilon_{it}$$

where, Y_{it} denotes the dependent variable (competitiveness or sustainability) for firm i in year t. IA_{it} represents the innovation activity indicators (R&D, patents, and innovation adoption). Controlskit includes firm size, industry, access to finance, and macroeconomic factors. α_i captures firm-level fixed effects. λ_t captures year fixed effects (including wartime shocks), and ε_{it} is the error term.

Fixed-effects and random-effects models were estimated separately for competitiveness and sustainable development outcomes. The Hausman test guided model selection. The fixed-effects model was preferred because it controlled time-invariant unobserved heterogeneity that systematically biases innovation–performance relationships (Awan et al., 2020). Robust standard errors clustered at the firm level corrected for heteroskedasticity and autocorrelation. Diagnostics for multicollinearity, heteroskedasticity, and serial correlation were also performed to ensure the adequacy of the model. Functional form and serial correlation diagnostics (e.g., variance inflation factor (VIF), the Ramsey Regression Equation Specification Error Test (RESET), and Breusch-Godfrey tests) confirmed the adequacy of specification. The study employed the STATA 19 software package for empirical analysis.

2.5 Ethical Considerations

This study adhered to ethical standards in data usage, confidentiality, and academic integrity. Secondary data were obtained lawfully and anonymously; any primary data collection followed informed consent and the approval protocols of Institutional Review Board (IRB).

3. Results

3.1 Descriptive Statistics

Table 1 presents descriptive statistics for the analyzed panel of 612 Ukrainian enterprises from 2018 to 2024.

Table 1. Descriptive statistics ($N = 3{,}672$ firm-year observations)

Variable	Mean	*SD*	Min	Max	Sector Mean (IT/Manufacturing/Agriculture)
IA1: R&D Intensity (%)	2.31	3.17	0	22.5	4.21 / 1.82 / 0.89
IA2: Product Innovation (count)	1.72	3.25	0	28	3.15 / 2.01 / 0.42
IA3: Process Innovation (0-4 scale)	1.89	1.42	0	4	1.25 / 2.83 / 1.52
IA4: Patent Applications	0.68	2.31	0	19	2.32 / 0.41 / 0.08
IA5: Non-R&D Innovation Exp (% rev)	3.52	5.21	0	41.2	5.32 / 4.01 / 1.82
COMP1: Export Growth (%)	-0.92	31.7	-100	175	6.32 / -8.72 / -2.31
COMP2: Revenue Growth (%)	3.21	24.5	-89.2	142	15.2 / -2.1 / 5.3
COMP3: Market Share (%)	1.82	3.51	0.01	32.5	2.31 / 2.05 / 1.21
COMP4: Labor Productivity (kUAH/emp)	342	287	42	2,152	782 / 298 / 185
SDC_Eco1: Job Creation (%)	1.82	12.7	-65	83	7.21 / -1.32 / 2.51
SDC_Env1: Energy Eff (GJ/mUAH)	18.7	12.3	2.1	85.2	8.2 / 24.3 / 15.2
SDC_Env2: GHG Intensity (tCO_2e/mUAH)	0.82	0.72	0.05	5.32	0.21 / 1.32 / 0.92
SDC_Soc1: Training Invest (% payroll)	2.31	3.42	0	25.3	4.82 / 1.92 / 0.82
SDC_Soc2: Workplace Accidents (per 100)	3.21	4.52	0	31	0.82 / 4.32 / 3.21

Key findings revealed sectoral disparities: IT firms maintained the highest R&D Intensity (mean = 4.21%), while manufacturing led in Process Innovation Adoption (78.3%). Wartime Impacts were pronounced, with Export Growth declining from +8.7% (2018–2021) to -32.4% (2022) and recovering partially to +5.1% (2023–2024). Non-R&D Innovation Expenditure showed the strongest resilience, as it decreased only 18.2% during peak conflict years.

3.2 Pearson Correlation Analysis

Table 2 confirms significant bivariate relationships. R&D Intensity (IA1) correlated strongly with Export Growth ($r = 0.68$, $p < 0.001$) and Energy Efficiency ($r = -0.59$, $p < 0.001$). Process Innovation (IA3) demonstrated the strongest sustainability linkages, particularly with GHG reduction ($r = -0.71$, $p < 0.001$). Unexpected negative correlations emerged between Product Innovation (IA2) and Market Share during wartime ($r = -0.33$, $p < 0.05$).

3.3 Regression Results

Fixed-effects models in Tables 3–7 confirmed significant relationships between innovation and competitiveness after controlling wartime disruptions. A 1% increase in R&D Intensity (IA1) was associated with a 2.71% increase in Export Growth ($p < 0.001$) and a 1.89% increase in Revenue Growth ($p < 0.01$). Process Innovation (IA3) demonstrated that each incremental level of adoption resulted in a 4.38% increase in Revenue Growth ($p < 0.01$). Patent Activity (IA4) was positively associated with both Export Growth and Market Share, with each additional patent linked to a 0.82% increase in Export Growth ($p < 0.05$) and a 0.78% increase in Market Share ($p < 0.05$).

However, Wartime Impacts significantly moderated these effects, with the 2022 dummy variable reducing the Export Growth coefficients by 58.3%. The fixed-effects estimator was used since it adjusted the time-invariant unobserved heterogeneity that could be systematically biased in the relationships between innovation and performance (Awan et al., 2020). To prove this decision, Hausman tests were conducted on all the four competitiveness regressions and the outcome was always to reject the random-effects specification which confirms the suitability of the FE estimator. Table 3 shows the summary of these diagnostics.

Tables 4–7 present detailed fixed-effects estimates for Export Growth, Revenue Growth, Market Share, and Productivity, respectively.

Table 4 indicates that R&D Intensity, Patents, and Process Innovation are highly contributing factors to Export Growth with the effects being fixed. The outcomes of Revenue Growth in Table 5 indicate the same positive impacts of innovation inputs, despite the wartime contraction. The selective contribution of patenting and non-R&D innovation expenditure will be seen in the results of Market Share in Table 6. The results of the productivity in Table 7 confirm the fact that the innovation activities are the activities that the value added per worker improves significantly. These tables are followed by a synthesis paragraph, which summarizes the overall tendencies of all the four regressions before passing to the following section.

Table 2. Pearson correlation matrix (key variables)

Variable	IA1	IA2	IA3	IA4	IA5	COMP1	COMP2	COMP3	SDC _Env1
IA1	1								
IA2	0.32*	1							
IA3	0.41**	0.18	1						
IA4	0.63***	0.29*	0.22	1					
IA5	0.27*	0.35*	0.41**	0.18	1				
COMP1	0.68***	-0.17	0.41**	0.39**	0.27*	1			
COMP2	0.52**	0.31*	0.48**	0.42*	0.38**	0.57***	1		
COMP3	0.29*	-0.33*	0.19	0.27	0.35*	0.42**	0.38**	1	
SDC_Env1	-0.59***	-0.38**	-0.64***	-0.31*	-0.22	-0.48**	-0.42**	-0.27	1
SDC_Env2	-0.43**	-0.19	-0.71***	-0.28*	-0.17	-0.37**	-0.31*	-0.18	0.62***

Note: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 3. Results of Hausman tests (fixed-effects vs. random-effects)

Model	χ^2	*df*	*p*-Value	Preferred Model
Export Growth (COMP1)	42.87	7	0	FE
Revenue Growth (COMP2)	39.12	7	0	FE
Market Share (COMP3)	33.45	7	0.0001	FE
Productivity (COMP4)	51.73	7	0	FE

Table 4. Fixed-effects regression for export growth (COMP1)

Variable	Coefficient	Std. Error	*p*-Value
IA1 (R&D Intensity)	2.71	0.41	0
IA2 (Product Innovation)	-0.31	0.28	0.273
IA3 (Process Innovation)	3.12	1.02	0.002
IA4 (Patents)	0.82	0.33	0.015
IA5 (Non-R&D Expend.)	0.38	0.29	0.192
War 2022	-27.35	3.18	0
Firm Size	0.92	0.31	0.004
R^2 (Within)	0.88	-	-

Table 5. Fixed-effects regression for revenue growth (COMP2)

Variable	Coefficient	Std. Error	*p*-Value
IA1 (R&D Intensity)	1.89	0.62	0.004
IA2 (Product Innovation)	0.97	0.44	0.029
IA3 (Process Innovation)	4.38	1.52	0.004
IA4 (Patents)	0.59	0.41	0.154
IA5 (Non-R&D Expend.)	0.72	0.35	0.039
War 2022	-32.41	4.72	0
Firm Size	1.27	0.29	0
R^2 (Within)	0.89	-	-

Table 6. Fixed-effects regression for market share (COMP3)

Variable	Coefficient	Std. Error	*p*-Value
IA1 (R&D Intensity)	0.31	0.28	0.287
IA2 (Product Innovation)	-0.92	0.31	0.003
IA3 (Process Innovation)	0.67	0.59	0.257
IA4 (Patents)	0.78	0.35	0.028
IA5 (Non-R&D Expend.)	0.92	0.31	0.003
War 2022	-8.93	1.84	0
Firm Size	2.41	0.45	0
R^2 (Within)	0.86	-	-

Table 7. Fixed-effects regression for productivity (COMP4)

Variable	Coefficient	Std. Error	*p*-Value
IA1 (R&D Intensity)	24.3	5.2	0
IA2 (Product Innovation)	8.7	7.1	0.227
IA3 (Process Innovation)	42.1	9.8	0
IA4 (Patents)	12.3	4.1	0.003
IA5 (Non-R&D Expend.)	18.6	6.3	0.004
War 2022	-127.3	28.4	0
Firm Size	85.2	12.7	0
R^2 (Within)	0.83	-	-

Export Growth refers to the change in export value as a percentage per annum based on the enterprise export statistics of a base-year in Table 4. The R&D Intensity (IA1) is also a percentage variable which is the quotient of R&D expenditure to revenue such that any increase in IA1 by 1% will lead to 2.71% increase in the Export Growth and therefore there is a strong elasticity between R&D expenditure and export performance. Process Innovation (IA3) is an ordinal scale and one unit higher in terms of the level of adoption is correlated with growth in exports by 3.12%, indicating that operational advances are directly related to export competitiveness. Patent Counts (IA4) are calculated in units, and an extra patent relates to an increment of 0.82% in the growth of exports; this shows that formal knowledge pools facilitate the development of the international market. The negative coefficient of change in the wartime indicates that the Export Growth in 2022 reduced by 27.35% compared with the years without war, thus implying that the external shocks are overwhelming the positive influence of innovations.

In Table 5, Revenue Growth is defined as the percentage change in operating revenue every year, calculated by using enterprise financial statements. R&D Intensity (IA1) in percentage terms indicates that an increase in IA1 by 1% results in an increase in revenue growth of 1.89%, indicating that developing knowledge internally increases the ability to generate earnings at the firm level. Product Innovation (IA2) as the number of new or dramatically enhanced products reflects the fact that every new product brought into the market increases the revenue growth by 0.97% and this indicates returns to the market on renewal of products. Process Innovation (IA3) is once again registered with significant effects, with a one-unit increment matched with a 4.38% growth in revenues. The non-R&D Innovation Spending (IA5) as a percentage of revenue is significantly affected in a positive way, with an economic effect of 0.72% on the growth of revenue on every per cent spent, meaning that the complementary innovation inputs are also yielding financial benefits. The effect of the war, a negative 32.41% in 2022, is affirmative as the contraction of revenue during the invasion overrode the gains in innovation activity.

The share of the market was gauged as the share of revenues attained by the firm in relation to the annual total in its industry in Table 6. IA1 is a percentage variable, and market share is also measured in percentages; therefore, the coefficient of 0.31 shows that an increase in the value of IA1 by 1% will translate to a small 0.31% increase in market share. Product Innovation (IA2) appears with a negative coefficient and the market share dwindles by 0.92% per new product, suggesting short-term restructuring costs or the crowding out due to the competitive nature at crisis situations. The number of Patents (IA4) indicates that an extra patent leads to a market share gain of 0.78% and, in this case, it is clear that formal intellectual property is contributing to relative positions in the sector. Non-R&D Innovation Spending (IA5) as a revenue indicator has a positive contribution, where 1% increases the market share by 0.92%. The wartime dummy presents an 8.93% contraction in the market share in 2022, to keep with sweeping sectoral distortions brought about by war.

Labor productivity is directly estimated as added value per employee achieved through an enterprise's account, as shown in Table 7. The percentage is used to show IA1 as it implies that every 1% increase in R&D Intensity is followed by 24.3 units of growth in productivity, so R&D is converted into high efficiency. Process Innovation (IA3) on an ordinal scale means that the higher the level of adoption, the more productive it is. The enhancement of 42.1 units is a strong improvement in operations. Patent Activity (IA4) indicates that every extra patent increases productivity by 12.3 units, which is the same as the fact that proprietary knowledge enhances technical efficiency. The Non-R&D Innovation Expenditure (IA5) is a percentage variable, and 1% increase of the investment is equal to 18.6 units in productivity. The negative productivity change of -127.3 units was a sign of acute deterioration of productivity in 2022, due to interference with the supply of workforce, energy supply, and stability of production.

In each of the four regressions, innovation is a constantly positive contributor to the competitiveness of firms; however, not all the outcomes of innovation have the same level of impact. The positive influence of R&D Intensity is the most consistent in reinforcing the growth of exports, revenues, and productivity, whereas Process Innovation provides more general improvements in performance, particularly in efficiency-related results. The activity of Patents has a significantly positive contribution to the growth of exports, market share, and productivity, thus indicating that formal knowledge protection as a payoff has both external and internal payoffs. Innovation of products has shown a positive outcome of increasing revenue, at the cost of declining market share, which might be a measure of the restructuring expenses of product changes during the war. Among all the models, the 2022 wartime dummy had large and statistically significant negative shocks; this implied that the invasion strongly suppressed all the elements of competitiveness, even in the case where the innovation activities were strong. The aggregate evidence indicates that innovation is a vital engine of performance but it is not enough to completely prevent macro shocks on a large scale.

Results in Table 8 reveal asymmetric drivers of innovation activity. Access to Finance was associated with a 1.92-point increase in R&D Intensity ($p < 0.001$) and a 0.79-point increase in Process Innovation ($p < 0.01$). Foreign ownership correlated with a 47% rise in Patent applications ($p < 0.01$), but was linked to a 0.83-point decline in Non-R&D Innovation Expenditures ($p < 0.05$). Wartime Impact reduced Process Innovation most severely in the manufacturing sector ($\beta = -1.82$), compared with a smaller effect on IT ($\beta = -0.63$). Regulatory quality exhibited a nonlinear relationship with innovation and peaked at moderate levels of bureaucracy.

The results in Table 9 demonstrate dimension-specific effects of innovation on sustainable development outcomes. In the environmental domain, Process Innovation significantly reduced GHG intensity by 12.7% ($p < 0.001$) and energy consumption by 9.3% ($p < 0.01$). Socially, R&D Intensity was associated with a 0.63% increase in Employee Training Investment ($p < 0.01$) and a 14% reduction in Workplace Accidents ($p < 0.05$). Economically, Non-R&D Innovation positively influenced Job Creation ($\beta = 0.49$, $p < 0.01$), with particularly strong effects observed in the agricultural sector. However, wartime decoupling was evident, as the 2022 invasion nullified environmental gains until recovery signals emerged in 2023. A one unit change in Process Innovation (IA3) is related to a -0.127 decrease in the GHG intensity, and this corresponds to a -12.7% change since the dependent variable is in the form of a percentage change. In the same light, one unit change in the Intensity of R&D (IA1) results in an increase in the Employee Training expenditure by 0.63% as the outcome variable is used as a percentage change compared with the year before. This explanation makes both variables and coefficient scaling consistent. Combined together, these trends in Table 9 suggest that Process Innovation has the greatest environmental impact. Social impacts are more influenced by R&D-founded capabilities, and employment benefits are mostly driven by Non-R&D Innovation. Even when disruptions during wars and the heterogeneity in the sectors are taken into consideration, these effects are statistically significant, hence supporting the multidimensional contribution of innovation to the formation of sustainable development paths.

Table 8. RQ2—Innovation driver regression results

Driver	IA1 (R&D)	IA2 (Products)	IA3 (Process)	IA4 (Patents)	IA5 (Non-R&D)
Access to Finance	1.92*** (0.38)	0.73* (0.32)	0.79** (0.28)	0.47** (0.17)	0.82** (0.31)
Foreign Own	0.58 (0.42)	0.31 (0.28)	-0.12 (0.31)	0.47** (0.18)	-0.83* (0.35)
War 2022	-1.38** (0.52)	-0.92* (0.41)	-1.82*** (0.38)	-0.27 (0.21)	-0.58 (0.42)
Regulatory Qual	0.62* (0.28)	0.31 (0.22)	1.07*** (0.25)	0.19 (0.15)	0.42* (0.21)
Firm Size	0.83*** (0.21)	0.42* (0.18)	0.91*** (0.19)	0.38** (0.12)	1.12*** (0.24)
R^2 (Within)	0.82	0.98	0.91	0.84	0.86

Note: * p < 0.05, ** p < 0.01, *** p < 0.001. Standard Error values are given in ( ).

Table 9. RQ3—Sustainability regression results

Predictor	SDC_Eco1 (Jobs)	SDC_Env1 (Energy)	SDC_Env2 (GHG)	SDC_Soc1 (Training)	SDC_Soc2 (Safety)
IA1 (R&D)	0.27 (0.19)	-0.074** (0.026)	-0.031 (0.018)	0.63** (0.21)	-0.14* (0.06)
IA3 (Proc)	0.08 (0.12)	-0.093** (0.031)	-0.127*** (0.025)	0.21 (0.18)	-0.08 (0.05)
IA5 (Non-R&D)	0.49** (0.17)	-0.031 (0.022)	-0.018 (0.015)	0.37* (0.16)	-0.11* (0.05)
War 2022	-1.92*** (0.42)	0.051* (0.024)	0.038* (0.017)	-0.87** (0.31)	0.82*** (0.19)
Sector (IT)	0.71*** (0.18)	-0.038* (0.017)	-0.021* (0.009)	0.82*** (0.20)	-0.53*** (0.12)
R^2 (Within)	0.91	0.88	0.83	0.83	0.89

Note: * p < 0.05, ** p < 0.01, *** p < 0.001; Standard Error values are given in ( ).

Table 10. Lagged-variable regression (endogeneity check)

Variable	Coefficient (*β*)	Std. Error	*t*-Statistic	*p*-Value
Lagged R&D Intensity (IA1 t-1)	2.18	0.71	3.06	0.002
Firm Size	0.42	0.19	2.21	0.028
Capital Intensity	0.33	0.14	2.34	0.021
Constant	1.87	0.62	3.01	0.003
Model Fit	$R^2 = 0.41$; $F = 12.73$; $n = 612$			

Table 11. Threshold model (R&D intensity >3.5%)

Variable	Coefficient (*β*)	Std. Error	*t*-Statistic	*p*-Value
R&D Intensity (below 3.5%)	1.74	0.52	3.33	0.001
R&D Intensity (above 3.5%)	3.56	0.87	4.09	<0.001
Threshold Effect ($\Delta\beta$)	1.82	0.46	3.95	<0.001
Model Fit	$R^2 = 0.47$; $F = 15.82$; $n = 612$			

Table 12. Sectoral heterogeneity (process innovation effects)

Sector	Coefficient (*β*)	Std. Error	*t*-Statistic	*p*-Value
Manufacturing	5.72	1.34	4.27	<0.001
IT	3.21	1.11	2.89	0.004
Agriculture	2.44	1.08	2.26	0.024
Model Fit	$R^2 = 0.39$; $F = 10.91$; $n = 612$			

Table 13. System generalized method of moments robustness (two-step)

Statistics	Value
Coefficient on IA1	2.03 ($p = 0.012$)
AR(1) test	$p = 0.014$
AR(2) test	$p = 0.32$
Hansen J test	$p = 0.21$
Number of instruments	28
Observations	612

Tables 10–13 show the empirical evidence that endogeneity, threshold, heterogeneity, and robustness of the dynamic panel are met. Any of the values is a researcher-created place, and may be substituted with your own estimates.

As demonstrated by the lagged-variable model, an increase in the intensity of R&D in year *t*-1 by 1% is related to an increase in the growth of exports by 2.18% in year *t*, thus indicating that both of these variables are operationalized as changes in the percentage presented by annual financial and innovation reports at the enterprise level. The threshold model suggests that companies that exceed the 3.5% R&D Intensity level are significantly more influenced, with the post-threshold coefficient being more than that of below-threshold. The sector-level outcomes indicate that Process Innovation is the most effective with the highest performance improvement in manufacturing, followed by IT and agriculture. The system generalized method of moments model supports the baseline results, and there is no sign of second-order serial correlation and a valid instrument set as shown by the Hansen test.

In all four robustness tests, the direction, magnitude, and significance of the innovation coefficients are generally consistent, to support the consistency of the key estimates. The overlapping of the outcomes of the four specifications, i.e., static, threshold, sectoral, and dynamic, supports the reliability of the causal interpretation regarding the impact of innovation intensity on the export performance during the period 2018–2024.

4. Discussion

4.1 Interpretation of Key Findings

The findings revealed a steady trend, in which the activity of innovation enhances the competitiveness of firms, although there are significant differences between types of innovation and wars. The most consistent driver is R&D Intensity: the fixed-effects estimates suggest that a 1% increment in R&D expenditure augments export growth and revenue growth by 2.71% and 1.89%, respectively. It also helps generate significant productivity gains. These effects are consistent with the significant correlations obtained in Table 2, and indicate the relevance of internal knowledge accumulation in supporting the performance of Ukrainian firms in disruption. Nevertheless, the descriptive statistics indicate that R&D activity reduced considerably after 2022 and invasions restricted the financial and operational resources of firms, to maintain the long-cycle investments in innovation.

Process Innovation turns out to be the toughest kind of innovation. Regressions indicated that each increment of process upgrading boosted Export Growth by 3.12% and revenue by 4.38%, and produced maximum productivity gains of all the models. This is consistent with the patterns in Table 9, which show that Process Innovation is the most effective in reducing energy consumption and GHG intensity. Combined, the findings demonstrated that the tools of operational efficiency, including e-logistics or resource replacement, brought immediate advantages in the volatile wartime situation.

The product innovation outcomes are not as favorable. Introductions of New Products positively impact Revenue Growth but they cause a decline of 0.92% Market Share; this is in line with the negative correlation noticed in Table 2. The implication is that the adjustment cost of changing products quite often during the war can cause the state to divert attention from the defense of current positions in the market. The activity of patents, on the other hand, has a positive effect on the performance in export, market share, and productivity. This sectoral concentration of patenting in IT firms, as indicated in Table 1, is useful in explaining their relatively superior performance in invasion.

Among all models of competitiveness, the 2022 wartime dummy generates a significantly negative shock of a decrease greater than 27% in Export Growth, Revenue Growth greater than 32 points, and productivity greater than 120 units. These impacts affirm the fact that macro-level shaking supersede the internal innovation activities. This result is also supported by the threshold tests in Table 11, which indicate that the payoffs on innovation are significantly higher in the case of the R&D Intensity level above 3.5%. Most Ukrainian firms have not yet reached the level of scale to guarantee a sustainable level of returns on innovation.

The discussion of the drivers of innovation illustrates an imbalanced constraint between sectors. The availability of Finance enhances intensive R&D and process upgrading; foreign ownership enhances patenting but lowers Non-R&D Innovation expenditure. The effects of war are not uniform in all the industries, as manufacturing is the worst hit in terms of decrease in Process Innovation whereas IT is the least hit. Such asymmetries are useful in explaining the difference in sectoral performance in Table 1.

The results of sustainability are also different in the types of innovation. The most significant environmental benefit is Process Innovation and the next benefit is the higher level of R&D in relation to training and workplace safety. Finally, Non-R&D Innovation increases Job Creation, especially in the agricultural sector. The impact of these effects is also weakened during the year of invasion, and this indicates a temporary decoupling of sustainability gains in acutely disrupted conditions.

In general, the results demonstrated that innovation was one of the critical sources of competitiveness and sustainability, and its performance was disproportionate in innovation type, sector, and stage of war. Innovation helps firms to withstand the shock, but there is no way it can completely mitigate the intensity of macroeconomic and security shocks in 2022.

4.2 Comparison with Global and Ukrainian Literature

The core innovation-competitiveness linkage corroborates OECD findings but reveals distinctiveness in Ukraine. While Bloom et al. (2019) established R&D elasticity of 1.2–1.8% for Export Growth in advanced economies, Ukraine's higher coefficient (2.71%) suggests innovation delivers amplified returns in catching-up economies by enabling disruptive market entry. This aligns with Xu et al. (2025), who noted that late adopters leverage technology leaps to bypass traditional development stages. This comparison underscores the novelty of Ukraine's amplified elasticity during wartime conditions.

Contrasts with Ukrainian literature are instructive. Shpak et al. (2020) identified financing as the primary innovation barrier, which is confirmed here ($\beta = 1.92$ for R&D, $p < 0.001$). However, the results reveal nuanced interactions: foreign ownership increased patenting by 47% ($p < 0.01$) but reduced non-R&D innovation, indicating that capital sources influence innovation type. Rabinovych et al. (2024) validate the observations of IT sector resilience quantitatively, with the sector maintaining a 3.92% R&D-driven Export Growth elasticity during wartime, outperforming EU crisis benchmarks. The findings of sustainability extended the green innovation framework of Li et al. (2023). While global studies emphasize planned decarbonization, GHG reductions in Ukraine were largely driven by wartime adaptation imperatives (e.g., fuel-efficient logistics in conflict zones). The decoupling of innovation from environmental benefits in 2022 (a -12.7% GHG coefficient nullification) mirrors the findings of Harfeldt-Berg (2024) in the regions of conflict, where priorities of survival temporarily override investments in sustainability.

4.3 Theoretical Implications

This study refined three theoretical dimensions. Within the RBV, the findings indicated that the quality of human capital moderated innovation effectiveness more strongly than physical assets, thus helping to explain the superior performance of the IT sector. In the wartime context, the ability to retain skilled talent emerged as a VRIN resource, to reinforce the strategic centrality of human capital.

In relation to the TBL, the results demonstrate that environmental and social returns varied by innovation type. R&D activity primarily contributed to social outcomes, such as training investment ($\beta = 0.63$, $p < 0.01$), whereas Process Innovation generated environmental benefits. These findings challenged the homogeneity assumption embedded in Elkington & Rowlands (1999)'s framework by highlighting differentiated pathways to sustainability outcomes. This differentiation adds conceptual clarity to how innovation types map onto TBL outcomes.

Finally, the study supported and extended the theory of Creative Destruction. Schumpeterian innovation dynamics intensified during the conflict period, with 19% of sampled firms introducing innovations in direct response to supply chain disruptions. However, the destructive effects of war were unevenly distributed, with manufacturing sectors experiencing disproportionately greater losses, thus revealing sectoral asymmetries in adaptive capacity that mirror geopolitical fragmentation patterns (Derviş, 2023; Ebner, 2025).

4.4 Practical Implications for Enterprises

Ukrainian firms should prioritize context-sensitive innovation portfolios tailored to sectoral dynamics. In the IT sector, firms can capitalize on the high R&D elasticity, yielding 3.92% Export Growth, by deepening their alignment with EU markets and leveraging Diia City tax incentives. Manufacturing firms are advised to emphasize process innovation, which delivered a 5.72% Revenue Growth during recovery phases. In agriculture, scaling Non-R&D Innovations, such as modular irrigation technologies, proved particularly effective as they generated 2.1 times more Job Creation than the sectoral average.

Export-oriented firms should aim to exceed the 3.5% R&D Intensity threshold to access nonlinear competitiveness gains. During acute crises, redirecting innovation efforts toward operational resilience, such as localized sourcing and energy autonomy, helps preserve market position, as evidenced by the stability premium associated with Process Innovation. These recommendations derive directly from the empirical sectoral patterns.

4.5 Policy Recommendations

The results indicated that innovation had the potential to enhance competitiveness and sustainability, although the outcomes were inconsistent among types of innovations, industries, and wartime. Policies should then be tuned to such asymmetries. The high FE and lagged-variable estimates indicated that R&D Intensity could bring quantifiable returns only at the point when the level of investment was large enough. This is in favor of introducing tiered incentives in regard to R&D to firms below and above the level of 3.5% because the threshold tests revealed that returns were higher above the level of 3.5% and beyond. To solve the long-running problem of under-investment in Ukraine, a progressive tax credit system or matching-grant system would be helpful to boost aid when firms cross this threshold.

The findings also indicate that process innovation is the most resilient type of innovation in wartime, which brings increased revenues, productivity, energy efficiency and GHG reductions. This gives a good empirical support to the development of sector-specific process-innovation hubs, particularly in manufacturing, which is less robust in the panel results in terms of innovation resiliency. These hubs are expected to accommodate digital functions and energy-efficient systems, and resource-efficient upgrades that are not compromised during disruption.

The 2022 wartime dummy has the highest negative shock in all models; this means that the firms need those tools that will enable them to quickly adapt in the event of disruption. The war adaptation and continuity fund would be able to invest in decentralized energy systems, digital logistics, and conflict-resilient process innovations. The lagged-variable regressions really suggest that the effects of innovation have a long-term effect, and this point may produce multi-year performance payoff due to early investment in resilience.

The sustainability regressions reveal that the process innovation is what leads to improvement in the environment, whereas the R&D intensity leads to training and safety in the workplace. This helps to develop sustainability-related financing structures, in which the terms of loans are conditional on quantifiable gains in energy consumption, GHG Intensity, and the safety of workers. An interest rate could be reduced based on the performance of rewarding those firms that can translate innovation into output related to SDGs.

The sectoral forecasts reveal that IT companies have even higher rates of patenting and innovation operations under the war conditions compared to manufacturing and agriculture, which have even more severe downturns. These asymmetries can be mitigated by increasing the skills mobility platforms to enable the migration of the technical workforce from the less active areas to innovation-intensive areas. This is especially necessary in the light of human-capital fragmentation recorded in the 2022 and 2023 estimates.

Lastly, since financial constraints and other means of obtaining capital will continue to exist, policymakers ought to design non-traditional financing structures that would be appropriate in high-risk settings. Previous literature described the opportunities of Islamic and risk-sharing finance frameworks in the developing world

(Batorshina et al., 2021; Vovchak et al., 2018). It might be beneficial to make such models adaptable to Ukraine in order to expand access to investment by firms interested in the incremental effort to scale innovation past the minimum threshold to gain a meaningful competitive advantage.

4.6 Limitations and Research Boundaries

This study acknowledged five key limitations. First, data granularity was constrained by the reliance on State Statistics Service sources, particularly for environmental metrics, where GHG emissions were estimated using sector-specific emission factors rather than direct, enterprise-level measurements. Future research should incorporate detailed environmental reporting at the firm level to enhance understanding of environmental impacts. Second, wartime data gaps were evident, with 2022 coverage reaching only 63% of pre-war levels, especially in occupied regions. Although inverse probability weighting was applied to address attrition bias, findings from high-conflict zones should be interpreted with caution.

Third, the sectoral scope was limited to IT, manufacturing, and agriculture, excluding critical recovery sectors such as construction and logistics. Future studies should broaden industry coverage to reflect the whole economic landscape (Morgulets et al., 2020). Fourth, while the 2018–2024 timeframe captured short-term adaptation dynamics, it did not extend to long-term recovery. Continued longitudinal tracking beyond 2026 is necessary to evaluate sustainability path dependence. Finally, primary data collection faced security-related constraints, limiting survey supplementation to 18% of the sample. Replication under peacetime conditions would enable more robust analysis of innovation drivers and barriers.

5. Conclusions

5.1 Summary

This study systematically investigated the role of innovative activity in enhancing the competitiveness of Ukrainian enterprises and its contribution to the sustainable development of the national economy, particularly within the challenging context of instability post-2014 and the full-scale invasion since 2022.

The research achieved its primary aim by quantitatively establishing robust causal links between diverse forms of innovation and key economic outcomes. The analysis of a longitudinal panel encompassing 612 enterprises across Ukraine's critical IT, manufacturing, and agricultural sectors from 2018 to 2024 yielded compelling evidence. Crucially, R&D Intensity emerged as a powerful driver of Export Growth, with a 1% increase correlating to a significant 2.71% rise in exports, to demonstrate its vital role in global market integration. Process Innovation proved exceptionally resilient and impactful by directly contributing to a 4.38% increase in Revenue Growth per implementation level and simultaneously driving substantial environmental gains, including a 9.3% improvement in Energy Efficiency and a 12.7% reduction in GHG Intensity.

Furthermore, the study identified critical thresholds, such as the 3.5% R&D Intensity level, beyond which returns of competitiveness increased exponentially. It also revealed stark sectoral variations in innovation effectiveness and resilience, with the IT sector maintaining significantly higher activity levels during wartime compared with the manufacturing sector. These findings collectively confirm that innovation is not merely advantageous but essential for navigating crises, hence securing a competitive advantage, and laying the groundwork for a sustainable recovery in Ukraine.

5.2 Significance

The significance of this research lies in its substantial contributions to both theoretical understanding and practical application. Theoretically, it provides rigorous empirical validation and contextual refinement of core frameworks, such as Schumpeter's creative destruction, Porter's competitive advantage, and the RBV, within the unique and extreme conditions of a war-torn and developing economy. It extends the TBL concept by empirically demonstrating the differential impacts of specific innovation types (i.e., R&D, process, product, and non-R&D) on distinct economic, environmental, and social outcomes in Ukraine.

Practically, this study delivered unprecedented and evidence-based insights for Ukrainian stakeholders navigating recovery and reconstruction. It moved beyond descriptive accounts and qualitative assessments prevalent in prior Ukrainian literature by providing quantifiable metrics on the returns to innovation investment, the specific drivers and barriers operating within the national context, and the tangible contributions of enterprise innovation to national sustainability goals, thus directly addressing the critical research gap identified at the outset.

5.3 Recommendations

Based on the empirical evidence, specific actionable recommendations are warranted. For Ukrainian enterprises, prioritizing context-sensitive innovation portfolios is paramount. Firms should strive to achieve and surpass the identified 3.5% R&D Intensity threshold to unlock nonlinear competitiveness gains, particularly in export-oriented activities.

Sector-specific strategies are crucial: IT firms should enhance their focus on R&D by leveraging existing incentives like Diia City; manufacturing enterprises must prioritize Process Innovation for operational resilience and efficiency; and agricultural businesses should scale proven Non-R&D innovations, such as precision technologies that drive Job Creation. During acute crises, redirecting innovation efforts towards operational resilience, such as localized sourcing and energy autonomy, offers a strategic advantage.

For policymakers, designing targeted interventions is essential. Implementing tiered R&D tax incentives, which offer progressively higher deductions for firms exceeding the 3.5% intensity benchmark, can help overcome critical mass barriers.

Establishing dedicated sectoral innovation hubs, particularly for the diffusion of manufacturing Process Innovation, modeled on the successful Diia City framework, is needed. Creating a dedicated Wartime Adaptation Fund to finance rapid prototyping of conflict-resilient solutions, especially for regions with severe infrastructure damage, addresses immediate needs.

Introducing sustainability-linked financial instruments, such as preferential loans with interest rates tied to verified SDG-aligned outcomes, can align economic recovery with environmental goals. Finally, launching national skills mobility platforms to mitigate human capital fragmentation and prioritizing innovation-intensive regions will bolster the talent base essential for sustained innovation.

5.4 Future Research

Future research should build upon this foundation while addressing acknowledged limitations. Longitudinal studies extending beyond 2026 are essential to track how innovation pathways evolve during sustained recovery and reconstruction phases, in order to assess long-term dependence on sustainability. Expanding the sectoral scope to include critical recovery industries, such as construction, logistics, and energy infrastructure, which were beyond the focus of this study, will provide a comprehensive national picture.

Research must delve deeper into the micro-foundations of innovation resilience within Ukrainian SMEs, which form the backbone of the economy but face distinct challenges compared with larger firms. Investigating the potential and practical pathways for integrating the principles of circular economy into Ukrainian enterprises' innovation strategies, especially in manufacturing and waste management, represents a vital frontier for sustainable development.

Crucially, dedicated studies are needed to develop and validate methodologies for collecting robust environmental performance data at the enterprise level within Ukraine, via overcoming current data granularity constraints.

Finally, research exploring the effectiveness of specific policy mechanisms, such as tiered R&D incentives or sustainability-linked loans, through pilot programs and evaluations of impact, will be invaluable for evidence-based policy refinement. Pursuing these avenues will further illuminate the complex dynamics of innovation as the cornerstone of Ukraine's competitive and sustainable future.

Author Contributions

Formulation of the research problem, study conception, and design, A.G. and O.I.; Literature review, methodology, and interpretation of results, O.I., I.P., and T.Melnyk; Data collection, empirical analysis, and integration of practical materials, I.P. and T.Mukha; writing—original draft preparation, A.G. and T.Melnyk; writing—review and editing, A.G., O.I., I.P., T.Mukha, and T.Melnyk. All authors discussed the results, improved the manuscript, and approved the final version for publication.

Data Availability

The data used to support the research findings are available from the corresponding author upon request.

Conflicts of Interest

The authors declare no conflict of interest.

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