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## ENTREPRENEURSHIP FOR SUSTAINABLE DEVELOPMENT IN UKRAINE: RESILIENCE OF THE INFORMATION AND COMMUNICATION SECTOR AMID THE WAR

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**Abstract.** *Entrepreneurship during ongoing war is a critical factor in achieving the Sustainable Development Goals, as it contributes to economic stability, facilitates adaptation to new social and security challenges, and lays the foundation for effective post-war recovery. The purpose of this study is to identify the key determinants of the development and resilience of entrepreneurship in Ukraine's information and communication sector during wartime and to assess its role in ensuring sustainable development for post-war period.*

*The research methodology relies on quantitative analysis using a Bayesian log-linear regression model. The dependent variable representing entrepreneurial resilience is business activity ( $Y_i$ ), measured by the total turnover of business entities in the sector of information and communication (thousand UAH). The independent variables include:  $X_1$  – number of active business entities in this sector (units);  $X_2$  – number of persons employed of business entities in the sector (persons); and  $X_3$  – secure Internet servers (units). The model was confirmed to be statistically adequate based on parameter estimation and diagnostic assessments.*

*The posterior estimates of the model coefficients revealed: (1) a negative and low-elastic relationship between business activity and the number of enterprises; (2) a positive and highly elastic relationship with employment; and (3) a positive but weakly elastic effect of digital infrastructure. Moreover, substantial regional disparities in entrepreneurial development in Ukraine's information and communication sector were identified, particularly after 2022, with a sharp decline in business activity among individual entrepreneurs in regions directly affected by hostilities.*

*The findings can inform the design of post-war recovery and sustainable development policy initiatives aimed not only at fostering new businesses creation, preserving highly skilled human capital, and advancing digital infrastructure, but also at strengthening the institutional and economic capacity of existing business entities, with consideration of regional specificities.*

**Key words:** *entrepreneurship, war, sustainable development, Bayesian modelling, information and communication sector, empirical analysis.*

**Problem statement.** Entrepreneurship is a critical driver of sustainable development, particularly in achieving the goals of sustained economic growth and decent work. Its development is inextricably linked to the expansion of business activity and the strengthening of economic resilience. In times of war, the role of entrepreneurship becomes even more pronounced, as it serves as a stabilizing force, facilitating economic continuity, fostering adaptability to emergent social and security challenges, and laying the foundation for effective post-war recovery. Within this context, the information and communication sector holds particular strategic importance. It not only sustains entrepreneurial activity under conditions of uncertainty but also acts as a catalyst for innovation, accelerates digital transformation processes, and enhances productivity across other sectors of the national economy.

To restore economic growth and enhance the resilience of the Ukraine's economy amid the ongoing war that began in 2014, the government has initiated a range of comprehensive policy initiatives aimed at fostering business activity, advancing digital transformation, broadening access to financial resources, and strengthening human capital. Within the framework of the Sustainable Development Strategy, Goals 8 "Decent Work and Economic Growth" and 9 "Industry, Innovation and Infrastructure" are identified as fundamental pillars for reinforcing Ukraine's entrepreneurial capacity. These goals play a critical role in facilitating structural economic transformation and promoting the adoption of information and communication technologies [1].

In line with these strategic objectives, the establishment of the Ukrainian Startup Fund (officially the Innovation Development Fund) in 2019 marked a significant institutional step toward supporting early-stage innovative ventures, enhancing the global perception of Ukraine, and promoting domestic technological solutions [2]. Moreover, Ukraine's post-war recovery plan prioritizes deepening digitalization, fostering a competitive and transparent business environment, advancing sectors with high value-added potential, and aligning with the principles of sustainable development [3]. Given the centrality of entrepreneurship in these policy agendas – particularly as a mechanism for post-war economic recovery and sustainable development – there is a critical need to examine its recent dynamics, with specific attention to the accelerated development of the information and communication sector.

**Analysis of latest research works and publications.** The contribution of entrepreneurship to fostering economic growth, sustainable development, employment generation, innovation, and post-war socio-economic recovery remains a central focus of contemporary scholarly discourse. This continued academic interest underscores the complex and multidimensional nature of entrepreneurial processes, particularly in the context of transformational changes in conflict-affected economies. Specifically, Apalkova et al [4], employing regression analysis, demonstrate that the ongoing war in Ukraine has heightened entrepreneurs' attention to sustainable development priorities in response to escalating economic challenges. Similarly, Kraus et al [5] propose a comprehensive set of policy initiatives aimed at revitalizing Ukraine's economy, with particular emphasis on accelerating the digitalization of entrepreneurship, fostering innovation, and improving the country's investment climate. Additionally, Kichurchak and Paslavskaya [6; 7] further substantiated the key policy initiatives designed to foster a more favourable business climate and mitigating human capital outflows, with particular attention to regional dimensions of sustainable development and the prospects for post-war recovery in Ukraine. Zomchak et al [8] emphasize that economic growth and increased foreign direct investment are critical drivers of entrepreneurial activity and the emergence of new businesses at the regional level in

Ukraine. From an infrastructural perspective, Matvienko-Biliaieva et al [9] underscore the importance of reducing digital inequality and expanding the IT sector as key elements of Ukraine's post-war recovery strategy. Collectively, these findings suggest that the success of Ukraine's post-war reconstruction efforts will depend heavily on the reinforcement of entrepreneurial capacity and its strategic alignment with broader sustainable development objectives.

Simultaneously, entrepreneurship in the information and communication sector exerts both direct and indirect effects on sustainable development and the broader economy. Jones et al [10] examined the contribution of information and communication technologies (ICTs) to advancing sustainable development, drawing on case studies of global corporations such as Ericsson and Microsoft, as well as industry associations including the GSMA and the Global Sustainable Electronics Initiative. Luo et al [11], employing a range of advanced econometric techniques – including benchmark regression, mediating effect model, spatial Durbin model, and dynamic models – investigated the multifaceted impacts of the digital economy on green innovation. Their analysis highlights the digital economy's direct, indirect, spatial, and non-linear effects, as well as the moderating role of digital policy frameworks. Additionally, Kichurchak [12] assessed the contribution of ICTs to the production of public goods. It was further explored the structural relationships among business entities in Ukraine's information and communication sector with regard to production, employment, and the creative economy at the regional level [13; 14]. Analysing data from 140 countries over the period 2000–2019, Nchofoung and Asongu [15] found that ICTs exert a positive and significant impact on sustainable development, contingent on geographical location and income group classification. Furthermore, Papaioannou [16], using difference-in-differences estimation, demonstrated that EU countries with higher ICT intensity experienced lower output losses in cyclical GDP during the COVID-19 pandemic. These findings collectively underscore that achieving sustainable development goals in the context of post-war economic reconstruction necessitates the creation of an enabling environment for entrepreneurship – particularly within the information and communication sector.

The advancement of ICTs has far-reaching implications for multiple dimensions of sustainable development and is actively reshaping the contemporary business environment. In particular, Wu et al [17] examined the role of ICTs in achieving the Sustainable Development Goals (SDGs), emphasizing the urgency of accelerating the adoption of innovative digital solutions as a key instrument for supporting national efforts to meet the SDGs by 2030. Rothe [18] offered a conceptual framework for assessing both the positive and negative impacts of ICTs on human well-being, highlighting their multidimensional influence on the environmental, economic, and social pillars of sustainability. Drawing on data from 24 OECD countries over the period 1980–2019, Shobande and Ogbeifun [19] identified multiple channels through which ICTs affect environmental outcomes, including education, transportation, foreign direct investment, regulatory quality, and institutional capacity. Complementarily, Andersson and Hatakka [20] provided a historical account of the evolution of the SDGs and critically analysed experimental approaches to leveraging ICTs, illustrating their potential to both advance and impede sustainable development. Andrés-Martínez and Alfaro-Navarro [21] demonstrated that while ICTs exert a measurable influence on the attainment of several SDGs, the capacity for their effective implementation varies significantly across countries. Similarly, Hojnik et al [22] established a positive correlation between environmental sustainability and digitalization in EU member states, although they found no statistically significant relationship between innovation and environmental

performance. In other words, digital transformation constitutes a critical precondition for achieving the SDGs and enhancing business resilience; however, its effective realization necessitates a balanced, context-sensitive, and systematically coordinated approach.

Meanwhile, amid the ongoing war, entrepreneurship in Ukraine is not only attempting to recover and adapt to war-related risks but is also assuming an increasingly proactive role in the country's post-war reconstruction. From the perspective of sustainable development, Simkiv et al [23] argue that entrepreneurship has been constrained in driving structural transformations within the Ukrainian economy – particularly at the regional level – posing a critical barrier to the transition toward an innovation-driven development model. Conversely, drawing on a survey of Ukrainian entrepreneurs conducted during 2022–2023, Smachylo [24] analysed the evolving landscape of challenges and transformations encountered by the Ukraine's business entities due to Russia's full-scale invasion, offering insights for strategic economic planning and post-war recovery. Using the synthetic control method, Audretsch et al [25] assessed the war's impact on small and medium-sized enterprises (SMEs) in Ukraine between 2014 and 2021, shedding light on the characteristics of their resilience. Based on a survey of 696 Ukrainian enterprises conducted between December 20, 2023, and January 8, 2024, Dligach and Stavytskyi [26] identified the primary factors contributing to business resilience amid the full-scale invasion and outlined strategic priorities for Ukraine's entrepreneurial recovery. Arbidane et al [27] examined the development pathways of green entrepreneurship in Latvia, proposing models for adapting these approaches to Ukraine's post-war recovery in alignment with sustainable development and green growth principles.

Simultaneously, a 2023 survey of 500 enterprises conducted under the project "Advisory Support to SMEs in Ukraine in the Context of the Military Crisis" enabled Hrebeshkova, Kyzenko and Verba [28] to identify the key causal relationships underpinning business resilience during wartime, with particular emphasis on an emergent approach to strategic management. Drawing on focus group discussions and in-depth semi-structured interviews conducted between March and May 2023, Lavreniuk et al [29] explored the main drivers of business relocation in Ukraine and highlighted the critical role of regional authorities in addressing the structural challenges associated with such transitions. Obłój and Voronovska [30] examined the adaptive responses of large enterprises to the war-induced crisis, emphasizing the relevance of prior crisis experience (e.g., the COVID-19 pandemic) in shaping corporate resilience and the emergence of a new "wartime normalcy". Overall, Russia's military aggression against Ukraine has exposed both structural vulnerabilities and strategic strengths within national entrepreneurial landscape, catalysing the development of more robust, sustainable models of resilience and recovery.

Despite the growing academic attention to the relationship between entrepreneurship, resilience, and the achievement of sustainable development goals, as well as the availability of a solid scientific and methodological framework and policy-oriented recommendations, the sector-specific dimensions of entrepreneurial resilience amid the ongoing war in Ukraine remain insufficiently examined. Accordingly, there is a pressing need for further empirical investigation to assess the adaptive capacities and determine the key drivers of resilience within the information and communication sector under wartime condition.

**Statement of objectives.** The purpose of this study is to identify the key determinants influencing the development and resilience of entrepreneurship in Ukraine's information and communication sector amid wartime conditions, and to evaluate its role in advancing sustainable development in the post-war context. In line with this objective, the following research hypotheses are proposed:

- H1: The level of business activity, measured by the total turnover of business entities in the sector of information and communication (thousand UAH), can serve as a valid indicator of sector's capacity to maintain operational functionality during the war.
- H2: Business activity in the information and communication sector is driven by quantitative factors, including the total number of enterprises, number of employees, and the level of digital infrastructure development.
- H3: The impact of war on the resilience of businesses entities in the information and communication sector may exhibits significant regional variation, influenced by underlying economic, social, and institutional factors.

**Research methods.** The analysis covers the period from 2010 to 2023, constrained by the availability and completeness of official statistical data, resulting in a relatively small sample size of only 14 annual observations. Under such conditions, the application of classical multivariate regression techniques is limited, as conventional estimators may yield unstable or biased results. Given the small-N context and the heightened uncertainty of economic processes induced by prolonged wartime conditions, this study adopts a Bayesian modelling approach as a more robust and methodologically appropriate alternative.

Bayesian modelling offers enhanced stability of parameter estimates in the context of small sample size, primarily due to its capacity to incorporate prior information. This methodological advantage enables the integration of existing theoretical or empirical knowledge into the estimation process through the specification of prior distributions that reflect informed assumptions regarding plausible parameter values. Unlike classical methods, Bayesian analysis yields not only point estimates but also their full posterior distributions, thereby enabling probabilistic interpretation of model parameters. This, in turn, facilitates a more nuanced understanding of the relationships between variables and enhances the robustness of inference under conditions of uncertainty.

Furthermore, the Bayesian approach is well-suited for models with nonlinear structural dependencies, including multiple interactions, and is capable of explicitly accounting for high levels of uncertainty through the incorporation of stochastic components. Accordingly, Bayesian modelling enables the generation of more robust and informative estimates of the influence of key determinants on the resilience of entrepreneurship in the information and communication sector under wartime conditions in Ukraine.

The choice of a multiple regression model to investigate the resilience of entrepreneurship in the information and communication sector within the framework of sustainable development is motivated by the need to capture potential nonlinear relationships between explanatory variables and the outcome variable, as well as to estimate their elasticities. The multiple regression framework enables the assessment of heterogeneous effects of individual predictors on the dependent variable, thereby allowing for a more accurate representation of complex systemic interactions. Moreover, the application of logarithmic transformation facilitates the linearization of multiplicative relationships, enhances the interpretability of the estimated coefficients as elasticities, and contributes to improved model stability and robustness.

Accordingly, a Bayesian multiple regression model will be employed to quantify the impact of various factors on the resilience of entrepreneurship in the information and communication sector, as expressed by the following equation:

$$Y_i = A \cdot \prod_{j=1}^n X_{ji}^{\beta_j} \cdot \eta_i, \quad (1)$$

where  $Y_i$  – the dependent variable for observation  $i$ ;  $X_{ji}$  – the  $j$ -th independent variable for observation  $i$ ;  $A = e^a$  – a constant (intercept);  $\eta_i$  – a multiplicative random error term, with

$\log(\eta_i) \sim N(0, \sigma^2)$ ;  $i$  – the number of observations,  $i=1, \dots, n$ ;  $j$  – the number of independent variables,  $j=1, \dots, m$ .

Equation (1) can be specified as a Bayesian log-linear regression model, formally expressed as follows:

$$\log(Y_i) = \log(A) + \sum_{j=1}^n \beta_j \cdot \log(X_{ji}) + \log(\eta_i), \quad (2)$$

where  $\log(A) = \alpha$ , with  $A = e^\alpha$  – a constant (intercept).

From a methodological standpoint, the annual data encompass both the pre-war period (2010–2013) and the war period (2014–2023). Although distinguishing between these periods is clearly important, a direct indicator variable representing the onset of war (e.g., a binary “war/no war” variable) was excluded from the final model due to the limited number of observations and the associated risk of overfitting. Previous attempts to incorporate such a variable resulted in unstable parameter estimates, increased uncertainty, and diminished interpretability of the results. Instead, the war’s impact is captured indirectly through the evolving dynamics of the relationships among variables across the study period. Consequently, the model facilitates the assessment of overall trends in business resilience within the information and communication sector while maintaining statistical robustness.

**Presentation of principal material of the research.** The ability of entrepreneurship in the information and communication sector to maintain operational functionality during wartime is assumed to be closely linked to the level of business activity, which is, in turn, influenced by the dynamics of enterprise growth, employment levels, and the development of digital infrastructure. Accordingly, the dependent variable is defined as  $Y_i$  – total turnover of business entities in the sector of information and communication (thousand UAH). The independent variables include  $X_1$  – total number of active business entities in this sector (units);  $X_2$  – total number of persons employed of business entities in the sector (persons);  $X_3$  – secure Internet servers (units). Based on these variables, the Bayesian model can be specified in both multiple and logarithmic (linearized) forms:

$$Y_i = A \cdot X_{1i}^{\beta_1} \cdot X_{2i}^{\beta_2} \cdot X_{3i}^{\beta_3} \cdot \eta_i \quad (3)$$

or

$$\log(Y_i) = \alpha + \beta_1 \cdot \log(X_{1i}) + \beta_2 \cdot \log(X_{2i}) + \beta_3 \cdot \log(X_{3i}) + \log(\eta_i) \quad (4).$$

To specify the model parameters, weakly informative prior distributions were employed to avoid overfitting and unnecessary model complexity. The regression coefficients ( $\beta_j$ ), the intercept ( $\alpha$ ), and the standard deviation of the residuals ( $\sigma$ ) assigned normal priors:  $N(0, 1)$ . Bayesian estimation was implemented using four independent Markov Chain Monte Carlo (MCMC) chains, each comprising 60,000 iterations, with the initial 2,000 iterations of each chain designated for the warm-up phase. This resulted in 58,000 post-warm-up draws per chain, yielding a total of 232,000 posterior samples without thinning (thin = 1), which served as the basis for posterior inference.

As shown in Table 1, the model yields high-quality posterior estimates, thereby supporting the robustness and reliability of the results. The Gelman-Rubin convergence diagnostic ( $\hat{R}$ ) equals 1.00 for all parameters, indicating complete convergence of the Markov chains. Moreover, the effective sample size exceeds 56,400 for each parameter, further reinforcing the stability of the estimates. The posterior estimates of the regression coefficients  $\beta_j$  lie entirely within their respective 95% credible intervals and do not include zero, which indicating a statistically significant and directionally consistent effect of the corresponding predictors on the dependent variable.

Table 1

**Bayesian Posterior Estimates and Convergence Diagnostics for the Log-Linear Multiplicative Regression Model**

Parameter	Posterior Mean	Se Mean	Posterior SD	Percentile					Effective Sample Size (n_eff)	Potential Scale Reduction Factor (Rhat)
				2.5th	25th	Median	75th	97.5th		
beta[1]	-0.694	0.001	0.282	-1.213	-0.881	-0.709	-0.524	-0.091	56439	1
beta[2]	1.795	0.001	0.241	1.288	1.645	1.804	1.956	2.245	58141	1
beta[3]	0.126	0.000	0.052	0.015	0.095	0.129	0.161	0.222	59610	1
alpha	0.231	0.003	0.976	-1.682	-0.428	0.234	0.890	2.144	107378	1
sigma	0.159	0.000	0.041	0.102	0.130	0.151	0.179	0.261	65503	1

Source: calculated based on [31, 32].

The obtained results can be interpreted as follows *Ceteris paribus*, a 1% increase in the number of enterprises in the information and communication sector is associated with an expected 0.694% decrease in total turnover. This inverse relationship may reflect the effects of excessive competition or market fragmentation under wartime conditions, wherein the growth in the number of business entities is not necessarily accompanied by a corresponding increase in demand or operational efficiency.

In contrast, the posterior coefficient for the second variable is positive, indicating that a 1% increase in the number of employed persons in the information and communication sector is associated with an expected 1.795% increase total turnover. This finding underscores the critical role of human capital in sustaining and revitalizing business activity under wartime conditions, highlighting its function as a key driver of entrepreneurial resilience and recovery.

Regarding the number of secure Internet servers, the posterior coefficient is also positive, suggesting that a 1% increase in the number of secure Internet servers is associated with a 0.126% increase in turnover within the information and communication sector. This result highlights the importance of digital infrastructure in maintaining business continuity during wartime, particularly in light of widespread transition to remote work, heightened cybersecurity threats, and elevated risks of physical infrastructure damage.

Based on the modelling results, it can be concluded that, in the context of the war in Ukraine, the increase in turnover among business entities in the information and communication sector is primarily driven by human capital and the robustness of digital infrastructure, whereas growth in the number of enterprises alone does not necessarily translate into higher sales volumes.

The estimation of the intercept  $\alpha$  and its associated credible interval reveals a considerable degree of uncertainty regarding the baseline logarithmic level of turnover among enterprises in the information and communication sector. The breadth of this interval suggests substantial variability in business performance that is not directly accounted for by the predictors included in the model. This may reflect unobserved heterogeneity among enterprises as well as heightened external volatility stemming from the ongoing war in Ukraine.

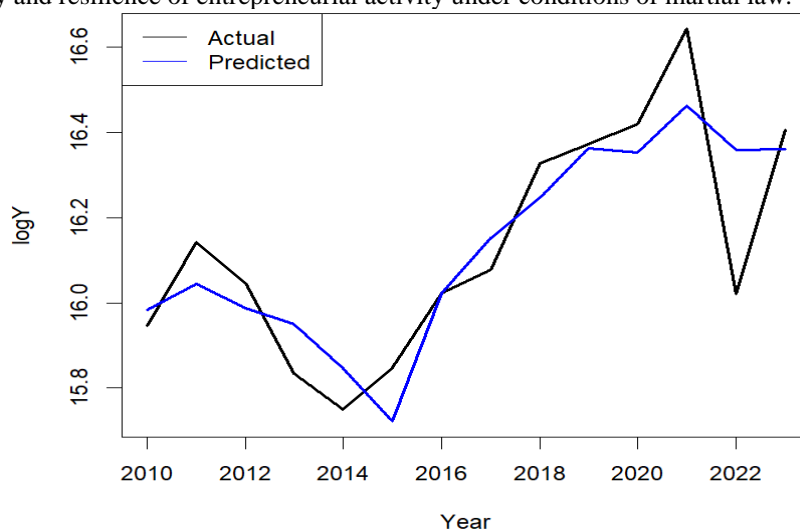
The posterior estimate of the residual standard deviation  $\sigma$  reflects a moderate degree of unexplained variation in the model. The narrow credible interval and high effective sample size underscore the robustness and stability of this estimate. However, this residual variation likely captures the influence of latent factors not explicitly modelled, such as political risks, institutional dynamics, regional disparities, and other constraints. These unobserved factors

may significantly impact the business activity of enterprises in Ukraine's information and communication sector but remain outside the scope of the current model specification.

Moreover, the standard errors of the posterior mean estimates (Se Mean) for all model parameters are sufficiently low (Table 1), indicating high accuracy and reliability of the parameter estimates. To assess the model's goodness-of-fit, the Bayesian p-value was computed and found to be 0.501. A value proximate to 0.5 suggests that the model adequately captures the empirical data, effectively reproducing the distributional characteristics observed in the sample. These results substantiate the appropriateness of the specified model structure and validate the underlying assumptions regarding the residual distribution.

The mean value of the Bayesian coefficient of determination ( $R^2$ ) is 0.637, suggesting that the model explains, on average, approximately 64% of the variance in the logarithmic turnover of business entities in Ukraine's information and communication sector. Furthermore, the 95% posterior credible interval for  $R^2$ , ranging from 0.394 to 0.814, demonstrates the model's robust explanatory power across various simulation scenarios. The median  $R^2$  value of 0.649 closely aligns with the calculated  $R^2$ , confirming the stability and consistency of the estimate. These results suggest that the constructed Bayesian model, based on the selected predictors, is both relevant and informative for analysing the resilience of business activity in the information and communication sector amid the ongoing war in Ukraine.

A visual comparison between the actual and predicted values (Fig. 1), derived from the Bayesian model demonstrates the model's capacity to accurately replicate the dynamics of business activity in Ukraine's information and communication sector, as measured by turnover. The model successfully captures key trends, including the growth observed during 2016–2019 and the partial recovery evident in 2023. Notable deviations between observed and predicted values are recorded during the years of major structural shocks – particularly in 2014 and, more significantly, in 2022 – coinciding with the onset and escalation of military aggression by the Russian Federation. Despite such variances, the model exhibits a satisfactory degree of alignment with empirical data, affirming its utility for assessing the adaptive capacity and resilience of entrepreneurial activity under conditions of martial law.



**Fig. 1. Comparison of Observed and Fitted Values of Log-Transformed Business Turnover in the Information and Communication Sector, Based on Bayesian Regression Results**

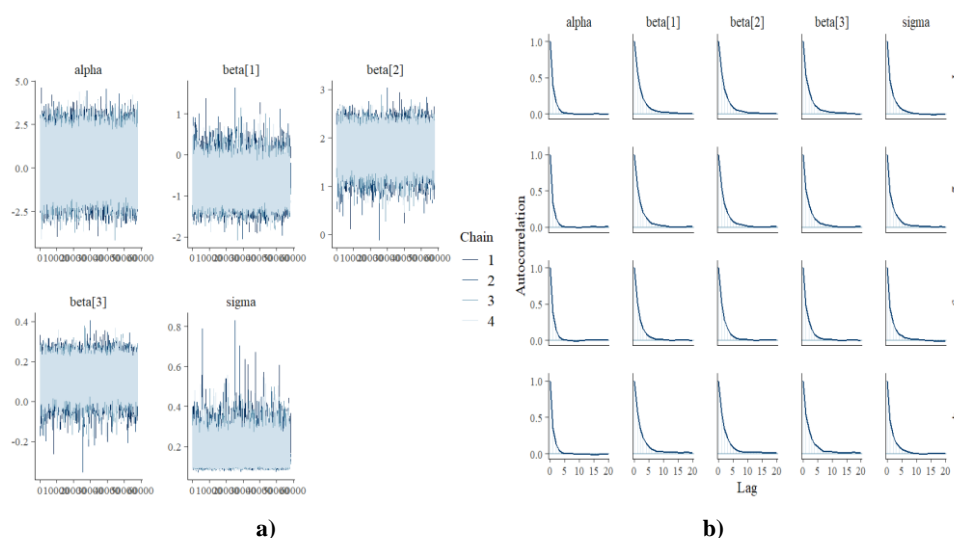
Source: calculated based on [31, 32].



Additional diagnostic assessments were performed to evaluate the predictive performance of the Bayesian model. The results of the Leave-One-Out Cross-Validation (LOO-CV), based on a  $232,000 \times 14$  log-likelihood matrix, yielded an expected log pointwise predictive density ( $\text{elpd}_{\text{loo}}$ ) of 4.0 with a standard error of 4.1. The effective number of model parameters ( $p_{\text{loo}}$ ) was estimated at 4.2 ( $\text{SE} = 2.1$ ), and the LOO Information Criterion (LOOIC) was -7.9 ( $\text{SE} = 8.2$ ). While the relatively high standard errors suggest a degree of uncertainty in the estimates, the overall results indicate a generally adequate out-of-sample predictive performance, supporting the interpretative validity of the model.

The Pareto  $k$  diagnostic results indicate that 13 out of 14 values (92.9%) fall within the “good” range ( $k \leq 0.7$ ), while one observation exhibits a slightly elevated value of  $k = 0.703$ , marginally exceeding the recommended threshold. This outlier corresponds to the year 2022, marked by the full-scale invasion of Ukraine by the Russian Federation, and likely reflects the structural shock associated with this unprecedented event. Given the small sample size and the exceptional nature of this observation, the deviation is not considered critical but should be acknowledged in the interpretation of the results. Overall, the model demonstrates sufficient stability and predictive adequacy for further empirical investigation.

The trace plots of the Markov Chain Monte Carlo (MCMC) simulations (Fig. 2a) for each model parameter exhibit satisfactory mixing behaviour, with no visible signs of stagnation or slow convergence within specific regions of the parameter space. The four independent chains for each parameter display tight overlap and consistent fluctuation around stable mean values, indicating the absence of any directional drift. Furthermore, the autocorrelation functions (Fig. 2b), calculated from the four MCMC chains, demonstrate a rapid decay at the initial lags, signifying high mixing efficiency and low serial dependence. These diagnostic results confirm the reliability and robustness of the MCMC-generated posterior samples, thereby supporting the validity of the Bayesian inference drawn from the model.

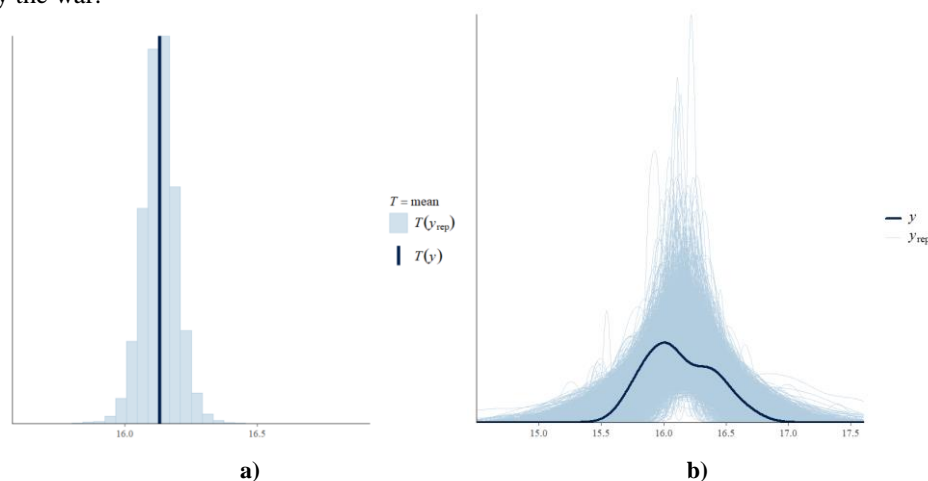


**Fig. 2. Traceplots and Autocorrelation Analysis of Posterior Samples for Model Parameters**

*Source: calculated based on [31, 32].*

The Posterior Predictive Check (PPC), based on the comparison of the test statistic  $T(y)=\text{mean}$  with the distribution of replicated test statistics  $T(Y_{\text{rep}})$  generated by the model, indicates that the model reliably reproduces the empirical mean of the observed data (Fig. 3a). Moreover, the estimated density of the observed data lies well within the distributional envelope (“cloud”) of simulated densities derived from 10,000 posterior predictive replicates (Fig. 3b). This result demonstrates the model’s capacity to accurately capture not only the central tendency but also the overall distributional shape and variability of the data. Taken together, these diagnostic outcomes affirm the model’s strong predictive performance and empirical validity.

To gain a more comprehensive understanding of the resilience of entrepreneurship in Ukraine’s information and communication sector, the results of Bayesian modelling should be contextualized within the broader spatial and temporal dynamics of sectoral development. Between 2014 and 2021 – prior to the full-scale invasion by the Russian Federation – the sector experienced marked expansion across key indicators, including the volume of products sold, the number of active business entities, and employment levels (Table 2). In light of the sector’s orientation toward high value-added activities and its strategic role in advancing sustainable development, this growth trajectory underscores its adaptive capacity and inherent resilience in the face of prolonged geopolitical and economic instability provoked by the war.



**Fig. 3. Posterior Predictive Check Density and the Test Statistic Comparison**

*Source: calculated based on [31, 32].*

However, in 2022–2023, entrepreneurial activity in the information and communication sector exhibited sensitivity to effects of the large-scale invasion, evidenced by a decline in the sector’s share of sales despite a modest increase in the number of enterprises and employment. These dynamics highlight the urgent need for effective state policy initiatives aimed at stimulating entrepreneurial activity within high-tech and strategically promising sectors of Ukraine’s economy during both martial law and the subsequent post-war recovery phase. Such policy initiatives will not only bolster economic resilience but also advance the achievement of sustainable development goals related to decent work, economic growth, innovation, and digitalization.

Given the regional asymmetry in the impact of the war (Table 2), ensuring sustainable business development necessitates a spatially differentiated approach both during and after the conflict. Specifically, between 2014 and 2023, city of Kyiv consistently maintained its leadership in terms of turnover, number of enterprises, and employment within Ukraine's regions, although these indicators have shown a declining trend since 2022. In contrast, the Lviv region, benefiting from its relative distance from the frontline, has demonstrated steady positive growth throughout the analysed period, reflecting a high degree of institutional adaptability and substantial potential for entrepreneurial stimulation. Despite ongoing hostilities, the Kharkiv region continues to hold a significant share of business activity within the information and communication sector, underscoring the resilience of its local ecosystem. Nonetheless, the observed decline in key indicators in 2023 relative to 2021 suggests emerging risks to migration outflows and security challenges attributable to the persistent war and proximity to the frontline.

Table 2

**Key Performance Indicators of Business Entities in the Information and Communication Sector Across Regions of Ukraine**

Region	Turnover of business entities, % of total thsd. UAH						Number of active business entities, % of total units						Number of persons employed of business entities, % of total persons					
	2014		2021		2023		2014		2021		2023		2014		2021		2023	
	Total	IIE	Total	IIE	Total	IIE	Total	IIE	Total	IIE	Total	IIE	Total	IIE	Total	IIE	Total	IIE
<b>Ukraine</b>	<b>2.37</b>	<b>0.48</b>	<b>3.53</b>	<b>1.65</b>	<b>2.49</b>	<b>0.0047</b>	<b>5.92</b>	<b>5.23</b>	<b>14.52</b>	<b>13.69</b>	<b>16.04</b>	<b>15.32</b>	<b>3.48</b>	<b>1.29</b>	<b>4.89</b>	<b>3.12</b>	<b>5.78</b>	<b>4.06</b>
Vinnitsya	0.03	0.02	0.08	0.04	0.0524	0.0002	0.20	0.19	0.41	0.39	0.49	0.47	0.07	0.05	0.11	0.09	0.15	0.13
Volyn	0.01	0.00	0.02	0.02	0.0039	0.0003	0.07	0.06	0.16	0.16	0.21	0.20	0.03	0.02	0.05	0.04	0.07	0.06
Dnipropetrovsk	0.07	0.04	0.17	0.13	0.0609	0.0008	0.48	0.44	1.16	1.11	1.31	1.27	0.18	0.11	0.32	0.26	0.42	0.34
Donetsk	0.04	0.02	0.05	0.03	0.0012	0.0001	0.18	0.16	0.25	0.24	0.18	0.18	0.09	0.04	0.10	0.06	0.05	0.05
Zhytomyr	0.02	0.01	0.04	0.03	0.0071	0.00001	0.11	0.10	0.26	0.25	0.30	0.29	0.05	0.02	0.08	0.06	0.09	0.08
Zakarpattia	0.01	0.00	0.02	0.02	0.0064	0.0001	0.07	0.06	0.16	0.14	0.19	0.18	0.03	0.02	0.04	0.03	0.06	0.05
Zaporizhzhya	0.02	0.01	0.06	0.05	0.0072	0.0001	0.21	0.19	0.49	0.46	0.47	0.45	0.09	0.05	0.14	0.11	0.14	0.12
Ivano-Frankivsk	0.01	0.01	0.03	0.03	0.0102	0.0001	0.08	0.07	0.27	0.26	0.34	0.33	0.03	0.02	0.08	0.06	0.11	0.09
Kyiv	0.04	0.02	0.13	0.10	0.0181	0.0003	0.24	0.22	0.81	0.78	0.97	0.95	0.08	0.05	0.21	0.18	0.28	0.25
Kirovograd	0.01	0.00	0.02	0.02	0.0060	0.0002	0.05	0.05	0.16	0.15	0.20	0.19	0.03	0.01	0.05	0.04	0.06	0.05
Luhansk	0.01	0.01	0.01	0.01	0.0001	0.000001	0.08	0.07	0.08	0.07	0.04	0.04	0.03	0.02	0.02	0.02	0.01	0.01
Lviv	0.09	0.04	0.28	0.16	0.21	0.0003	0.57	0.53	1.49	1.44	1.72	1.67	0.23	0.12	0.40	0.32	0.53	0.44
Mykolayiv	0.01	0.01	0.04	0.03	0.0057	0.00004	0.17	0.16	0.36	0.34	0.37	0.36	0.05	0.04	0.09	0.08	0.10	0.09
Odesa	0.07	0.03	0.11	0.08	0.0318	0.0003	0.30	0.27	0.74	0.70	0.82	0.78	0.15	0.07	0.22	0.16	0.27	0.21
Poltava	0.01	0.01	0.04	0.03	0.0117	0.00004	0.11	0.09	0.31	0.29	0.37	0.35	0.04	0.03	0.09	0.07	0.12	0.09
Rivne	0.01	0.01	0.02	0.02	0.0038	0.0001	0.07	0.07	0.20	0.19	0.24	0.23	0.03	0.02	0.06	0.05	0.08	0.06
Sumy	0.01	0.01	0.03	0.02	0.0040	0.0001	0.07	0.07	0.21	0.20	0.25	0.24	0.03	0.02	0.06	0.05	0.08	0.07
Ternopil	0.01	0.00	0.02	0.02	0.0087	0.0001	0.06	0.05	0.18	0.17	0.22	0.21	0.03	0.01	0.05	0.04	0.07	0.06
Kharkiv	0.13	0.07	0.31	0.21	0.12	0.0005	0.88	0.82	1.88	1.81	1.91	1.86	0.30	0.21	0.50	0.41	0.57	0.49
Kherson	0.01	0.01	0.02	0.02	0.0005	0.00001	0.09	0.08	0.18	0.17	0.13	0.13	0.03	0.02	0.05	0.04	0.04	0.03
Khmelnyskiy	0.01	0.01	0.03	0.02	0.0049	0.0001	0.07	0.06	0.23	0.22	0.29	0.28	0.03	0.02	0.06	0.05	0.09	0.08
Cherkasy	0.01	0.01	0.05	0.04	0.0144	0.0002	0.11	0.10	0.34	0.33	0.41	0.40	0.04	0.03	0.09	0.08	0.12	0.11
Chernivtsi	0.01	0.00	0.02	0.02	0.0068	0.00003	0.07	0.06	0.15	0.14	0.18	0.18	0.03	0.02	0.04	0.03	0.06	0.05
Chernihiv	0.01	0.01	0.03	0.03	0.0047	0.00004	0.09	0.08	0.24	0.23	0.28	0.27	0.04	0.02	0.06	0.05	0.08	0.07
City of Kyiv	1.72	0.14	1.91	0.48	1.88	0.0009	1.46	1.15	3.81	3.41	4.15	3.80	1.77	0.27	1.91	0.76	2.15	1.00

\*IIE – including individual entrepreneurs. Source: calculated based on [31, 32].

Regarding the Donetsk and Luhansk regions, the period following 2022 has seen a notable decline in turnover, whereas the shares of employed persons and the number of business entities have remained relatively stable. This pattern likely reflects that some enterprises maintain their registered legal addresses in these regions despite temporarily

suspending operations, while employees retain their positions through adaptive strategies or informal relocation.

Other regions of Ukraine have experienced moderate growth in business activity within the information and communication sector, alongside a noticeable sensitivity to turnover declines triggered by the full-scale invasion of the Russian Federation in February 2022. Consequently, at the regional level, achieving sustainable development goals that emphasize entrepreneurship revitalisation necessitates the implementation of targeted policy initiatives. These should focus on advancing digitalization through support for start-ups and the innovation ecosystem, enhancing digital skills within the human capital, and ensuring safe working conditions for the labour force.

On the other hand, individual entrepreneurs constitute a vital segment of entrepreneurial activity within Ukraine's information and communication sector. Between 2014 and 2021, they accounted for nearly half of the total turnover in this sector at the regional level, while representing over 60% of registered enterprises and employed personnel (Table 2). However, during 2022–2023, a pronounced decline in individual entrepreneur activity was observed across most Ukrainian regions, attributable to the impacts of the full-scale war. This trend may reflect increased market fragmentation within the information and communication service market, alongside greater resilience and adaptability exhibited by medium and large enterprises under wartime conditions. These findings align with the Bayesian modelling results, particularly the negative coefficient associated with the independent variable  $X_1$ , indicating an inverse relationship between turnover and the number of enterprises.

The dynamics of individual entrepreneurship development in Ukraine's information and communication sector highlight its pronounced sensitivity to military risks. Key factors contributing to this vulnerability include mobilisation conditions, the transformation of cooperation models driven by the shift to remote employment through international digital platforms or legal entities registered abroad, and tax uncertainties related to applicable taxation regimes. To advance sustainable development goals, it is advisable to activate regional economic policy that focus on developing mechanisms for military risks insurance, enhancing digital entrepreneurship infrastructure, and ensuring access to educational, consulting, and financial resources aimed at strengthening the resilience and innovative capacity of small businesses amid conditions of uncertainty.

The regional characteristics of business development in the information and communication sector further corroborate the findings of the Bayesian regression analysis, which indicates that growth in business activity across regions is associated with a reduction in the number of enterprises alongside the preservation of employment levels. Despite the challenges posed by the full-scale war in 2022, the sector exhibited relative stability and demonstrated an ability to undergo structural transformation, thereby averting collapse. In this regard, post-war recovery efforts grounded in sustainable development should prioritize high-tech sectors of the economy at both the national and regional levels, with particular emphasis on preserving human capital and advancing digital infrastructure. Concurrently, there is an urgent need to restore the attractiveness of entrepreneurial activity for individual entrepreneurs, recognizing their critical role as drivers of regional economic and social revitalization.

**Conclusions and perspectives of further research work.** Thus, empirical evidence confirms that entrepreneurship constitutes a pivotal factor in advancing sustainable development goals amid the ongoing war in Ukraine, particularly by supporting employment, fostering economic growth, enabling sectoral transformation, and driving the production of high value-added goods. The case of enterprises within the information and communication

sector exemplifies this resilience, demonstrating the sector's capacity to maintain relative stability and sustain business activity throughout the 2014–2023 period despite the adverse conditions imposed by the ongoing war.

The results of the Bayesian log-linear regression model indicate that business activity in Ukraine's information and communication sector, as measured by turnover of business entities, is significantly influenced by the number of enterprises, the number of employees, and the level of digital infrastructure development. A negative and low-elastic relationship between business activity and the number of enterprises was observed, suggesting that mere quantitative growth in entrepreneurship exerts a limited effect. This finding likely reflects the predominance of small and micro-enterprises, which generally exhibit lower productivity levels. Consequently, post-war recovery and sustainable development policy initiatives should prioritize not only the stimulation of new businesses formation but also the strengthening of the institutional and economic capacities of existing enterprises.

Conversely, the positive and highly elastic coefficient associated with the number of employed persons underscores the critical role of human capital in sustaining the sector. This finding emphasises the necessity of supporting flexible employment arrangements and implementing targeted policy interventions aimed at retaining and developing highly skilled professionals, particularly in the context of forced migration induced by the ongoing war in Ukraine. The variable representing digital infrastructure development exhibited a positive but low-elastic relationship with business activity, indicating an inertial effect digitalisation. Nonetheless, it confirms that the availability of robust digital infrastructure remains a fundamental prerequisite for the long-term sustainability and growth of entrepreneurship within the information and communication sector.

Furthermore, significant regional disparities have been observed in the development of entrepreneurship within the information and communication sector during the ongoing war. Following 2022, a pronounced decline in business activity among individual entrepreneurs was particularly evident in regions directly impacted by hostilities. Conversely, regions located farther from the front line exhibited greater resilience in terms of enterprise numbers and employment levels. These findings underscore the necessity for region-specific policy interventions aimed at bolstering entrepreneurial capacity in less affected areas, while simultaneously fostering the revival of entrepreneurial activities in severely impacted regions. Such initiatives essential components for a successful post-war recovery grounded in sustainable development principles.

Despite the valuable insights yielded by this study, several limitations should be acknowledged. The analysis spans the period from 2010 to 2023, which constrains the ability to comprehensively assess the long-term impacts of the ongoing war and the prospects for post-war recovery. Moreover, potential institutional changes that may indirectly influence entrepreneurial development were not incorporated into the analysis. Further research would benefit from extending the temporal scope, incorporating higher-frequency data such as quarterly or semi-annual observations, and utilizing enterprise-level microdata to provide a more granular understanding of entrepreneurship dynamics.

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## ПІДПРИЄМНИЦТВО ДЛЯ СТАЛОГО РОЗВИТКУ УКРАЇНИ: СТІЙКІСТЬ СЕКТОРУ ІНФОРМАЦІЇ ТА КОМУНІКАЦІЇ В УМОВАХ ВІЙНИ

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**Анотація.** Підприємництво в умовах війни є важливим чинником досягнення цілей сталого розвитку, оскільки сприяє збереженню економічної стабільності, адаптації до нових соціальних і безпекових викликів, а також створює основу для ефективного повоєнного відновлення. Метою дослідження є виявлення головних детермінант розвитку та стійкості підприємництва у секторі інформації та комунікації України під час війни та визначення його ролі у забезпеченні сталого розвитку для повоєнного відновлення.

Методологія дослідження базується на кількісному аналізі із застосуванням байєсівської логлінійної регресійної моделі. Залежною змінною, що відображає стійкість підприємництва в умовах війни, виступає ділова активність  $Y_i$ , яка визначається як загальний обсяг реалізованої продукції суб'єктів підприємництва у секторі інформації та комунікації (тис. грн.). Незалежними змінними виступають  $X_1$  – кількість активних суб'єктів підприємництва в цьому секторі (одиниць);  $X_2$  – кількість зайнятих у суб'єктів підприємництва у секторі інформації та комунікації (осіб);  $X_3$  – кількість захищених інтернет-серверів (одиниць). Модель виявилася статистично адекватною згідно з результатами оцінки параметрів та діагностичних перевірок.

Результати моделювання засвідчили на такі апостеріорні оцінки коефіцієнтів у байєсівській логлінійній регресійній моделі: (1) від'ємний та низькоеластичний зв'язок між діловою активністю та кількістю підприємств; (2) додатний та високоеластичний зв'язок із чисельністю зайнятих; (3) додатний, але низькоеластичний вплив цифрової інфраструктури. Проведений додатковий аналіз виявив суттєві регіональні диспропорції у розвитку підприємництва у секторі інформації та комунікації в умовах війни, особливо після 2022 р., з різким скороченням ділової активності серед індивідуальних підприємців у регіонах, які зазнали прямого впливу бойових дій.

Отримані результати можуть бути використані для розроблення заходів політики повоєнного відновлення та сталого розвитку, орієнтовані не лише на стимулювання створення нових підприємств, збереження висококваліфікованого людського капіталу та розвиток цифрової інфраструктури, й на посилення інституційної та економічної спроможності чинних суб'єктів господарювання з урахуванням регіональної специфіки.

**Ключові слова:** підприємництво, війна, сталий розвиток, байєсівське моделювання, сектор інформації та комунікації, емпіричний аналіз.

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