

Econometric assessment of determinants of industrial structural transformation in the Carpathian region in wartime

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Purpose. The purpose of the article is to identify and econometrically evaluate the determinants of structural transformation in the industrial complex of the Carpathian region in wartime.

Methodology. The study is based on the estimation of panel regression models, where the dependent variable is a vector of shares of individual industries in total industrial output, and the independent variables include indicators of foreign trade, capital investments, FDI, innovation activity, the labor market, and domestic consumption.

Findings. Foreign trade factors were established as key drivers of growth in the shares of transport equipment manufacturing and electrical equipment manufacturing, confirming the significant integration of regional enterprises into European value chains. For electricity, gas, and steam supply, a substantial stimulating effect of high-tech imports was revealed, meeting the critical need of the sector for modern equipment to modernize power generating capacity and restore infrastructure. The statistical insignificance of investments and innovations for most medium- and high-tech industries (except the food industry) was identified, indicating that enterprises operate under contract assembly conditions relying on imported technologies amidst a capital deficit. The validity of the efficiency wage theory was confirmed: an increase in labor costs stimulates output in the food industry, furniture manufacturing, and equipment repair due to enhanced labor productivity. The impact of domestic consumption aligns with Engel's law, highlighting the export orientation of most industrial branches in the Carpathian region.

Originality. The study deepens the theoretical and methodological framework and provides empirical justification for the determinants of regional industrial structural transformation. It proves that analyzing the shares of individual industries is more informative than using an aggregated index, as it reveals not only the scale of inter-industry redistribution but also the qualitative direction of development for specific industrial sectors.

Practical value. The strategic priorities for industrial policy were identified: transitioning from tolling operations to in-house R&D and dual-use technologies; developing industrial parks; implementing war risk insurance; adopting an efficiency wage model; and engaging local enterprises in reconstruction programs.

Keywords: industrial structural transformation, Carpathian region, panel regression, determinants of structural shifts, exports, imports, investments, innovations, domestic consumption, employment.

Introduction

Prolonged armed conflicts are among the most critical factors disrupting the functioning of regional economies. Their consequences encompass not only the destruction of production and transport infrastructure, but also changes in sectoral economic structures, capital flows, labor markets, and vectors of economic cooperation. Under these conditions, structural transformation processes unfold that are both forced – driven by the imperative for enterprises to adapt to new environments – and adaptive, linked to seeking new sources of growth and enhancing regional economic resilience.

The Carpathian region, encompassing the western regions of Ukraine, plays a distinct role in the ongoing war. Due to its relative safety compared to territories directly affected by military actions, it has become a hub for business relocation, population inflows, and the concentration of new investments. Simultaneously, the region confronts numerous challenges arising from supply chain disruptions, constrained labor resources, shifting demand patterns, escalating operational costs, and the need for swift realignment of production capacities toward the requirements of the wartime economy and future national reconstruction. These processes drive structural shifts in the industry of the Carpathian region, the scale and direction

of which are shaped by interconnected economic, social, demographic, institutional, and geopolitical factors.

In this regard, identifying the key determinants of industrial structural shifts is of paramount importance. It provides a foundation for highlighting sectors that are most sensitive to changing conditions in domestic and international markets, while also serving to refine mechanisms for economic adaptation during a prolonged war.

Literature Review

Structural transformations are a subject of research at both macroeconomic and regional levels. Foreign scientists pay significant attention not only to examining the theoretical foundations of structural economic shifts, but also to the empirical analysis of key determinants driving these transformations. Economic complexity theory indicates that industrial structure and the interconnection of productive capabilities create the foundation for technological modernization and economic growth (Hausmann and Hidalgo, 2011). A study conducted by A. van Dam and K. Frenken (2020) confirms the importance of industrial diversification and product complexity for a country's economic development.

Among the primary determinants of structural shifts, scholars highlight foreign direct investment, which affects industrial structure through mechanisms such as knowledge transfer, modernization of local technological and innovation capabilities, productivity growth, competitiveness, and export upgrading (Fu et al., 2021). Under globalization, technological progress—specifically digital transformation and knowledge-intensive manufacturing—has become a major driving force of industrial modernization, enhancing the efficiency of traditional industries and facilitating the transition to higher value-added segments (Chen, 2025). Based on panel data analysis for 142 countries, A. Teixeira and A. Pinto (2026) identified scientific diversification as an important driver of economic growth, expanding the knowledge base for industrial recombination.

The degree of a country's integration into global value chains, its modernization trajectories, and its capacity to capture an increasing share of value added within the national economy determine the growth benefits of specialization. Considering this, Timmer et al. (2019) justified the need to analyze countries' occupational activities within global production networks and proposed an index based on comparing occupational labor incomes, accounting for the occupational structure of the labor force as a factor in generating export value added. Another essential component of the driving mechanism behind structural transformation includes shifts in consumption patterns, income elasticity of demand, and the impact of foreign trade on industrial structure (Liu J., 2020).

The issue of structural shifts in the Ukrainian economy is extensively examined by domestic scholars. Experts from the National Institute for Strategic Studies, based on an evaluation of industrial structural imbalances, identified state policy priorities to drive structural transformations aimed at post-war economic recovery and modernization (Sobkevych et al., 2026). Nazarkevych (2019) analyzed how various factors influence the national economic structure, generating multiplier and accelerator effects. Shevchenko (2023) examined structural changes in Ukrainian industry during wartime and justified the necessity of state support for strategic industrial branches to drive economic transformations under resource constraints.

Aksyonova (2024) analyzed the sectoral structure of industry and assessed disparities in the industrial development of Ukrainian regions using the coefficient of variation for per capita industrial sales volume. Scholars from the Institute of Regional Research analyzed industrial transformations across Ukrainian regions, identifying the highest concentration of industrial production in industrial regions characterized by top levels of product innovativeness and returns on innovation investment (Ishchuk et al., 2023). Based on a regional diagnostics of industrial

sector structural transformations, Ishchuk (2023) concluded that «new industrial centers» have been forming in western and central Ukraine since 2014, with these transformational processes accelerating under full-scale war. Shults and Lutskiv (2024) constructed a multifactor regression model and revealed a significant direct impact of the unemployment rate, net migration rate, share of sales by small enterprises, share of innovative product sales, regional R&D intensity, and business density on the index of structural shift intensity in regional economies.

An analysis of scientific literature reveals that the issue of industrial structural transformation at the regional level remains insufficiently explored regarding the econometric evaluation of economic factors affecting industrial structure. Therefore, a pressing scientific task is to identify the determinants of regional industrial structural changes using econometric models that not only determine the factors driving the intensity of proportional changes, but also allow for evaluating the direction and qualitative nature of such transformations.

Purpose of the Study

The objective of the article is an econometric evaluation of factors influencing the structural transformation of industry in the Carpathian region in wartime. To achieve this goal, the following tasks were set: justifying the key components of the econometric model and specifying variables; conducting a regression analysis using panel data to identify the key determinants of shifts in the sectoral structure of industry in the Carpathian region; formulating conclusions and recommendations regarding the strategic development vectors for the Carpathian region under war conditions.

Methodology

An econometric assessment of the determinants of industrial structural transformation in the Carpathian region is conducted based on a methodological approach involving the modeling of individual industry shares in total industrial sales as dependent on changes in domestic consumption, investment, innovation, foreign trade, and employment indicators. Instead of an abstract index of structural shift intensity, the share of a specific industry is utilized as the dependent variable. This approach enables the identification of factors that drive the expansion of high-tech industries versus those that reinforce a raw-material orientation of the economy.

The established system of determinants incorporates indicators that capture structural transformations driven by both supply-side and demand-side shifts:

- 1) domestic consumption – reflects the capacity of regional markets and their ability to absorb manufacturing output;
- 2) foreign trade – characterizes the integration level of industries into global value chains, their international competitiveness, and import substitution potential;
- 3) investment – determines the dynamics of technological renewal, capital intensity, and the potential for modernizing the material and technical base of industries;
- 4) innovation activity – reflects the knowledge intensity of production, technological adaptability, and the capacity of industries to generate high value added;
- 5) employment and wages – reflect inter-industry human capital flows and qualitative changes in the labor force structure.

The methodology for analyzing sectoral structural shifts in industry involves specifying and estimating a series of panel regression models, where a separate panel model is constructed for each k -th industrial sector ($k = 1, \dots, K$). Accordingly, for period t and industry k in the Carpathian region (comprising Zakarpattia, Ivano-Frankivsk, Lviv and Chernivtsi oblasts) the specification of the panel regression model is expressed as follows:

$$Y_{i,t}^{(k)} = \alpha^{(k)} + \beta_1^{(k)} \cdot \text{Cons}_{i,t} + \beta_2^{(k)} \cdot \text{Trade}_{i,t} + \beta_3^{(k)} \cdot \text{Inv}_{i,t} + \beta_4^{(k)} \cdot \text{Innov}_{i,t} + \beta_5^{(k)} \cdot \text{Labor}_{i,t} + \mu_{i,t}^{(k)} + \lambda_{i,t}^{(k)} + \varepsilon_{i,t}^{(k)}, \quad (1)$$

where: $Y_{i,t}^{(k)}$ – is the share of the k -th industrial sector in the total volume of industrial products sold in region i in year t (dependent variable); $\text{Cons}_{i,t}$, $\text{Trade}_{i,t}$, $\text{Inv}_{i,t}$, $\text{Innov}_{i,t}$, $\text{Labor}_{i,t}$ – are vectors of explanatory variables for the 5 respective factor blocks; $\mu_{i,t}^{(k)}$ – represents unobserved individual (regional) effects that are time-invariant; $\lambda_{i,t}^{(k)}$ – represents time effects (macroeconomic shocks common to all regions in year t); $\varepsilon_{i,t}^{(k)}$ is the idiosyncratic error term.

The use of a panel data structure ($N \cdot T$, where N is the number of regions and T is the time period) offers substantial advantages over conventional cross-sectional or time-series data, as it controls for unobserved heterogeneity (μ_i). Furthermore, combining spatial and time dimensions significantly reduces multicollinearity among regressors and enhances the efficiency of t -statistics.

Each of the five vectors of independent variables reflects fundamental mechanisms of resource reallocation within the process of structural transformation, as graphically detailed in the structural-logical framework of the evaluation (Figure 1). The architecture of the framework includes:

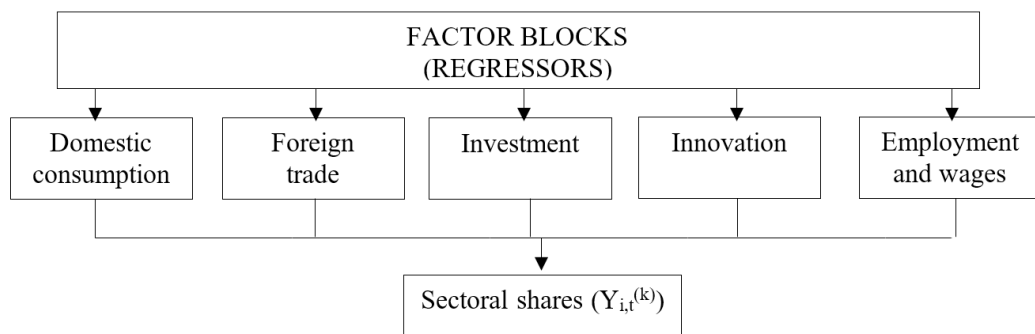


Fig. 1. Structural-logical framework for assessing the impact of factors on sectoral industrial transformation based on panel data

Source: developed by the author.

1) independent variables – five factor blocks (consumption, trade, investment, innovation, employment) that capture the key drivers of industrial sector development;

2) dependent variables – sectoral shares of individual industries ($Y_{i,t}^{(k)}$), reflecting proportional shifts in industry under the influence of these factors.

The vector of dependent variables includes the shares of major industrial sectors in the total volume of industrial products sold: Y_1 – mining and quarrying; Y_2 – manufacture of food products, beverages, and tobacco products; Y_3 – manufacture of textiles, wearing apparel, leather, and related products; Y_4 – manufacture of wood and paper products, and printing; Y_5 – manufacture of chemicals and chemical products; Y_6 – manufacture of machinery and equipment; Y_7 – manufacture of computer, electronic, and optical products; Y_8 – manufacture of electrical equipment; Y_9 – manufacture of machinery and equipment n.e.c.; Y_{10} – manufacture of motor vehicles, trailers, semi-trailers, and other transport equipment; Y_{11} – manufacture of furniture, other manufacturing, and repair and installation of machinery and equipment; Y_{12} – electricity, gas, steam, and air conditioning supply; Y_{13} – water supply, sewerage, waste management, and remediation activities.

The vector of variables characterizing domestic consumption and market capacity (Cons) encompasses the following indicators: share of sales of goods produced in

Ukraine in wholesale trade turnover (Cons₁); share of food products in wholesale trade turnover (Cons₂); share of non-food products in wholesale trade turnover (Cons₃); physical volume index of retail trade turnover of retail trade enterprises (in constant prices) relative to the previous year (Cons₄). These variables reflect the absorptive capacity of the domestic market and the degree of import substitution: growth in retail trade turnover primarily stimulates consumer goods industries (food and light industry), whereas shifts in the proportions of food and non-food products in wholesale turnover illustrate structural changes governed by Engel's law (an increasing share of non-food products in wholesale turnover signals a shift in consumer demand toward durables, construction, and household appliances, thereby driving the development of manufacturing and high-tech industrial sectors).

The vector of foreign trade indicators (Trade) includes the following variables: export (Trade₁) and import (Trade₂) growth rates relative to the previous year; share of high-tech products in merchandise exports (Trade₃) and imports (Trade₄); export-to-import ratio (Trade₅). This component of the econometric model reflects international competitiveness and the degree of regional integration into global value chains. The share of high-tech products serves as an indicator of trade «quality» and structural shifts resulting from the expanding shares of manufacturing and knowledge-intensive industries alongside a declining role of raw-material sectors.

Investment capital (Inv) is characterized by the following indicators: index of capital investments relative to the previous year (Inv₁); share of industry in total capital investments (Inv₂); FDI growth rate relative to the previous year (Inv₃); share of industry in total FDI (Inv₄). The rationale for including these variables in the model lies in capital accumulation being the material basis for structural realignment (according to neoclassical growth models). Domestic and foreign direct investment (FDI) serve as the primary drivers for commissioning new production capacities and modernizing the technological process.

Innovation activity (Innov) comprises two variables: share of innovation-active industrial enterprises in the total number of industrial enterprises (Innov₁); growth rate of innovation expenditure (Innov₂). The importance of this determinant stems from the fact that innovation-active enterprises generate higher value added, reallocating market shares and resources toward progressive, high-tech sectors.

The labor market and labor costs (Labor) are characterized by indicators such as: share of industrial employment (Labor₁); share of labor costs in total industrial production costs (Labor₂). Rising labor costs indicate high labor intensity or increasing production costs. Under such conditions, an industry can maintain its market share only through gains in labor productivity; otherwise, it will lose its market standing.

The regression analysis utilizes statistical data for 2014–2024, published in statistical compendiums (Regions of Ukraine (2016), Regions of Ukraine (2021)), on the official websites of the Main Departments of Statistics in Zakarpattia (Main Department of Statistics in the Transcarpathian region, URL: <https://www.uz.ukrstat.gov.ua/>), Ivano-Frankivsk (Main Department of Statistics in Ivano-Frankivsk Region, URL: <https://www.ifstat.gov.ua/INDEX.HTM>), Lviv (Main Department of Statistics in Lviv Region, URL: http://database.ukrcensus.gov.ua/statbank_lviv/Dialog/statfile_n.asp?lang=1) and Chernivtsi oblasts (Main Department of Statistics in Chernivtsi region, URL: <http://www.cv.ukrstat.gov.ua/>), as well as the National Bank of Ukraine (National Bank of Ukraine, URL: <https://bank.gov.ua/ua/statistic/sector-external#5>).

Results and Discussion

According to the panel regression results, the strongest relationship was identified between the share of transport equipment manufacturing in the total volume of industrial products sold (Y_{10}) and the share of high-tech products in

merchandise exports of the analyzed regions (Trade₃), as evidenced by the highest correlation coefficient (R=0.944) among all statistically significant relationships obtained (Table 1). The coefficient of determination indicates that during 2014–2024, the share of transport equipment manufacturing in the structure of industrial sales was 89.1% dependent on changes in the proportion of high-tech exports, and 10.9% on factors not accounted for in the panel regression model. A 1 percentage point (p. p.) increase in the share of high-tech exports led to a 0.414 p.p. growth in the share of transport equipment manufacturing, proving the high sensitivity of the industry to EU market conditions. This dependence stems from the presence of major enterprises operating in the Carpathian region (e.g., Leoni, Bader, Fujikura), which import components and export automotive parts to the EU.

At the same time, no statistically significant relationship was found between the share of transport equipment manufacturing in total industrial sales and indicators reflecting investment, innovation, domestic consumer demand, employment, or labor costs in industry. The lack of impact from these factors is explained by the strong export orientation of the sector's enterprises: sales volumes depend on order schedules from European automotive corporations, R&D solutions are imported from parent companies within global value chains, and production facilities operate under long-term contracts, rendering the industry independent of the intra-regional

Table 1
Results of the assessment of the impact of factors on the industrial structure of the Carpathian region in 2014-2024

Factor features	Dependent variable						
	Y ₂	Y ₈	Y ₁₀	Y ₁₁	Y ₁₁	Y ₁₂	Y ₁₂
Model	<i>Model 2</i>	<i>Model 8</i>	<i>Model 10</i>	<i>Model 11.1</i>	<i>Model 11.2</i>	<i>Model 12.1</i>	<i>Model 12.2</i>
Number of observations	33	40	38	38	38	41	41
Intercept	41,52*** (8,609)	-5,32*** (1,086)	-3,36*** (0,804)	5,96*** (0,680)	5,03*** (0,744)	12,03*** (4,429)	49,47*** (6,946)
Cons ₁	-	-	-	-0,078*** (0,011)	-	-	-
Cons ₂	-	-	-	-0,027** (0,012)	-	0,732*** (0,106)	-
Trade ₃	-	0,086*** (0,011)	0,414*** (0,024)	0,054*** (0,007)	0,04*** (0,012)	-0,77*** (0,197)	-
Trade ₄	-	-	-	-	-	0,91*** (0,276)	-
Trade ₅	-	3,21*** (0,757)	-	-	-	-	30,52*** (4,643)
Inv ₂	-	0,083*** (0,025)	-	-	-	-	-
Inv ₄	-0,26** (0,096)	-	-	-	-	-	-
Innov ₁	1,05*** (0,338)	-	-	-	-	-	-
Labor ₁	-1,30*** (0,261)	-	-	-	-0,19*** (0,024)	-	-
Labor ₂	0,34** (0,151)	-	-	-	0,064*** (0,021)	-	-0,97*** (0,136)
R	0,797	0,870	0,944	0,909	0,906	0,851	0,816
R ²	0,637	0,758	0,891	0,826	0,820	0,725	0,667

* – statistical error rate (p-level) ≤10%; ** – statistical error rate (p-level) ≤5%;

*** – statistical error rate (p-level) ≤1%.

Source: calculated by the author.

economic environment. Consequently, shifts in local consumption do not affect sales in this sector, capital investment or FDI do not directly alter production line capacity, and output volume is independent of workforce numbers or wage levels, as labor serves as an adaptive resource aligned with set production targets.

A direct relationship was found between the share of furniture, other products, repair of machinery and equipment (Y_{11}) in total sales and the share of high-tech products in exports of goods ($Trade_3$). During 2014–2024, a downward trend was observed in both the dependent and independent variables. Therefore, the results obtained can be interpreted as follows: a decrease in the share of high-tech products in exports of goods by 1 p.p. led to a decrease in the share of furniture, other products, repair of machinery and equipment by 0.054 p.p. (according to model 11.1) or by 0.04 p.p. (according to model 11.2). At the same time, both models are characterized by high statistical significance, which is confirmed by the corresponding values of the correlation coefficients for the first ($R=0.909$) and the second models ($R=0.906$). This dependence can be explained by the fact that in the conditions of an unfavorable investment climate and military risks, business entities limited capital expenditures for technical re-equipment and maintenance of equipment, which led to a simultaneous decrease in the share of both sectors in product sales.

Conversely, an inverse relationship was observed between the share of electricity, gas, and steam supply in the total volume of products sold (Y_{12}) and the share of high-tech products in exports, which reflects economic transformations in the Carpathian region in 2014–2024. According to model 12.1, a decrease in the independent variable by 1 p.p. led to an increase in the dependent variable by 0.77 p.p., and the value of the correlation coefficient ($R=0.851$) indicates the existence of a significant relationship between these variables. Thus, a decrease in the share of high-tech exports in the studied period was accompanied by a simplification of the sectoral structure of the region's industry. The reduction in the output of high-tech products occurred against the backdrop of repeated tariff increases and rising cost indicators in the energy and gas supply sector. The decrease in the share of high-tech exports led to a relative increase in the nominal share of the infrastructure and energy sector, since the demand for its products is inelastic. This confirms that deindustrialization and the loss of export technological potential increase the dependence of the region's economy on basic monopoly sectors.

A direct effect of the export-to-import ratio on the share of electrical equipment production (Y_8) and the share of electricity, gas, and steam supply in total sales (Y_{12}) was found. This factor had no effect on the shares of other industries. According to model 8, the direct relationship between the export-to-import ratio and the share of electrical equipment production ($\beta = 3.21$; $p < 0.05$) in combination with the downward dynamics of both indicators in most regions of the Carpathian region (except Ivano-Frankivsk oblast) during 2014–2024 reflects the process of negative structural changes in both foreign trade and industry. The positive value of the regression coefficient shows that a decrease in the export-to-import ratio by 0.1 units led to a decrease in the share of electrical equipment production in the structure of sales by 0.321 p.p. The correlation coefficient ($R=0.87$) confirms the presence of a significant relationship between the variables. This dependence is due to the fact that the production of electrical equipment is an export-oriented sector of the region, which is integrated into global value chains. Accordingly, the reduction in the output of this product due to the destruction of logistics in wartime conditions and the increase in prices for imported materials and components led to a deterioration in the region's foreign trade balance. The exception of Ivano-Frankivsk oblast only confirms the revealed pattern: the deterioration of the foreign trade balance directly reflects the loss of technological and export potential of the electrical engineering industry.

In model 12.2, the positive value of the regression coefficient for the independent explanatory variable «export-to-import ratio» ($\beta = 30.52$; $p < 0.05$) indicates that a

0.1-unit increase in this ratio drives a 3.052 p.p. increase in the share of electricity, gas, and steam supply within the structure of industrial products sold in the Carpathian region. The correlation coefficient ($R = 0.816$) demonstrates a substantial relationship between these variables. It should be noted that the share of energy supply during 2014–2024 increased across all oblasts of the region, with the exception of Ivano-Frankivsk oblast (where it slightly decreased from 40.6% to 39.3%). At the same time, the export-to-import ratio in Lviv and Chernivtsi oblasts significantly decreased, despite intermittent periods of growth; in Zakarpattia oblast, it remained virtually unchanged (consistently staying below 1); whereas in Ivano-Frankivsk oblast, it generally saw a slight increase (from 1.04 in 2014 to 1.09 in 2024), remained consistently above 1, and peaked at the highest levels in the Carpathian region during certain periods (1.27 in 2015, 1.41 in 2016, and 1.19–1.17 in 2020–2023).

Under conditions where the export-to-import ratio declined in Lviv and Chernivtsi oblasts but increased in Ivano-Frankivsk oblast, the positive relationship between its variation and the share of the energy sector in the industrial structure of the Carpathian region is explained by several econometric and economic factors. First, panel regression accounts for variation both over time and across regions; therefore, the combination of the highest values of the independent variable with the highest values of the dependent variable in Ivano-Frankivsk oblast creates a strong positive cross-regional correlation, driving an overall positive vector ($\beta = 30.52$) for the entire panel dataset. Second, until June 2024, when Burshtyn TPP was completely destroyed by Russian missiles (Yalivets, 2024), the energy sector of the Carpathian region – owing to the operation of the «Burshtyn TPP Energy Island» prior to synchronization with ENTSO-E in 2022 and subsequent cross-border electricity flows – served not only as supporting infrastructure but also exported substantial volumes of electricity. Consequently, during peak electricity export periods, the sales value of the energy sector grew rapidly, driving a corresponding increase in the share of energy within the structure of industrial products sold, which contributed to an improved regional trade balance and a higher export-to-import ratio. Third, in Lviv and Chernivtsi oblasts, periods of deteriorating foreign trade balances coincided with contractions in industrial output sold. Accordingly, a declining export-to-import coverage ratio in these regions could be accompanied by a relative decline in the capacity of industrial enterprises to pay for energy at market tariffs, leading to a temporary drop in the share of electricity, gas, and steam supply during export downturns.

The absence of a statistically significant effect of the export-to-import ratio on the shares of mining and quarrying and other manufacturing sectors in the Carpathian region indicates a high concentration of foreign trade activity and segmentation within the regional industrial complex. As the findings demonstrate, the export-to-import ratio can be considered a substantial factor driving development for industrial sectors (Y_8 and Y_{12}) that genuinely define the region's foreign trade profile. Conversely, most industrial sectors are either locally oriented (where domestic demand and consumer purchasing power are key) or operate within import-dependent supply schemes, where export growth is accompanied by an equivalent import of raw materials and inputs. Furthermore, the statistical insignificance of the export-to-import ratio's impact on traditional sectors during 2014–2024 stems from wartime logistical and inflationary shocks, which served as more prominent determinants of these sectors' shares in total industrial output. The share of high-tech products in merchandise imports affected only the proportion of electricity, gas, steam, and air conditioning supply in total industrial sales (Y_{12}): a 1 percentage point (p.p.) increase in the independent variable contributed to a 0.91 p.p. increase in the dependent variable (table 1, model 12.1). The substantial direct relationship ($R = 0.851$) between the share of the energy supply sector in the industrial structure and the share of high-tech imports is explained by the modernization of generating and distribution capacities funded through imports of advanced energy equipment.

As a result of the regression analysis, no statistically significant impact of the share of high-tech goods in imports on the share of other industries in the total volume of products sold was found. The lack of a relationship between the share of high-tech imports and the share of most manufacturing industries in the Carpathian region is explained by the consumer nature and non-commercial purpose of high-tech imports, limited technological absorption by enterprises and the functioning of electrical engineering enterprises within the framework of tolling contracts. A significant part of the goods belonging to the category of «high-tech imports» (computer equipment, smartphones, telecommunications and medical equipment, dual-purpose equipment, military property) is imported for the needs of households, the IT sector, medicine or defense. Imports of industrial equipment (CNC machines, robotics) are extremely limited, since most industrial enterprises in the region do not have the financial resources to carry out comprehensive modernization. Machine-building plants in the region import high-tech components within the framework of tolling schemes, and assembled modules are immediately re-exported in accordance with the terms of the contract, which makes it impossible to increase intra-regional added value due to imported technologies.

The results of econometric modeling demonstrate that foreign trade factors are key determinants of the development of electrical engineering and the energy sector of the Carpathian region. On the other hand, the direct relationship between these variables confirms that expanding the share of electrical equipment manufacturing within the region's industrial structure and leveraging the cross-border nature of the regional power grid (integration with ENTSO-E) improves the foreign trade balance.

According to the results of panel regression, an inverse dependence of the share of furniture production, repair and installation of machines in the total volume of products sold (Y_{11}) was found on the change in the share of sales of goods produced in Ukraine in wholesale trade ($Cons_1$) and the share of food products in wholesale trade ($Cons_2$). With an increase in these variables by 1 p. p., the dependent variable decreased by 0.078 p.p. and 0.027 p.p., respectively (table 1, model 11.1). The strong relationship between the dependent and independent variables is confirmed by the high value of the correlation coefficient ($R=0.909$). The inverse dependence of the share of furniture production, repair and installation of machines and equipment on the indicated indicators of wholesale trade indicates a high sensitivity of locally oriented industries of the Carpathian region to changes in the quality of domestic demand. The growth of the share of food in wholesale trade illustrates the effect of Engel's law in the context of a crisis reduction in income, when the need to optimize costs forces households and businesses to abandon the purchase of durable goods and equipment repair services. The inverse effect of the share of domestic products in wholesale trade is explained by the dominance of agricultural and raw materials in domestic trade and the dependence of furniture production, repair and assembly of machines on imported components, materials and accessories.

According to model 12.1, a change in the share of food products in wholesale trade ($Cons_2$) directly affected the share of electricity, gas, steam supply in the total volume of products sold (Y_{12}): an increase in the independent variable by 1 p. p. contributed to an increase in the dependent variable by 0.732 p. p. A significant statistical relationship between these variables is confirmed by the value of the correlation coefficient ($R=0.851$). The growth of the share of food in wholesale trade in the Carpathian region in 2014-2024 indicates the orientation of domestic demand for essential goods, which, in the context of a reduction in the output of technological products, leads to an increase in the share of the energy sector, which is characterized by inelastic demand for energy from utilities and the population. In addition, servicing food trade requires significant electricity costs to ensure a continuous technological process of processing, freezing and storing products.

The impact of wholesale trade indicators ($Cons_1$, $Cons_2$) was statistically insignificant regarding the shares of other industrial sectors in total sales, which

is explained by their export orientation or monopolistic nature, rendering them independent of fluctuations in the domestic consumer and wholesale markets. Export-oriented sectors (manufacture of electrical equipment, manufacture of transport equipment) operate within European value chains, and their sales volumes are determined by external contracts rather than the structure of domestic wholesale trade. The statistical insignificance of the impact of wholesale trade indicators on the share of the food industry in total industrial sales indicates a transformation in food distribution channels. Food industry enterprises sell their products primarily through retail chains and direct exports. Moreover, the food industry produces essential goods characterized by inelastic demand; thus, the high stability of physical output volumes does not depend on domestic wholesale market conditions. The mining and quarrying, chemical, textile, and wood processing industries are isolated from the domestic wholesale consumer goods market, accounting for the independence of their shares in total industrial sales from wholesale trade indicators. Textile manufacturing operates primarily under tolling schemes with immediate re-export of finished goods to the EU, whereas the wood processing and chemical industries are oriented toward direct exports or direct deliveries to industrial consumers. Output volumes in the mining sector are determined by the natural resource base and direct supplies of products to energy and construction enterprises.

Changes in the share of industry in total capital investments (Inv_2) directly affected the proportion of electrical equipment manufacturing in total industrial sales: a 1 percentage point (p.p.) increase in the independent variable led to a 0.083 p.p. increase in the dependent variable. The value of the correlation coefficient ($R = 0.87$) indicates a substantial relationship between these variables. This result confirms the high capital intensity of the sector and its capacity to efficiently absorb investment resources to expand production capacity. The share of food production in total industrial sales was inversely related to changes in the share of industry in total FDI (Inv_4): a 1 p.p. increase in the independent variable resulted in a 0.26 p.p. decrease in the dependent variable. This relationship can be explained by a structural crowding-out effect arising from the concentration of foreign investments in machinery manufacturing alongside negligible inflows into other sectors, particularly the food industry. Directing a relatively larger share of FDI into machinery manufacturing fosters faster growth rates in this sector, thereby increasing its proportion in total industrial sales while relatively diminishing the share of the food industry (even under conditions of stable or growing physical output). For instance, in Zakarpattia oblast, the share of machinery manufacturing in industrial sales during 2014–2024 increased from 40.8% to 59.3%, whereas the proportion of the food industry in the structure of sales declined from 10% to 4.8%.

The absence of a statistically significant effect of investment factors on the shares of other industrial sectors may be attributed to insufficient investment volumes to generate substantial structural shifts in total industrial sales. For most traditional sectors, capital investments are made primarily to maintain operational status rather than to expand production capacities. Meanwhile, electronics and transport equipment manufacturing enterprises mostly operate under tolling arrangements and utilize production lines provided by parent companies, which are often not captured in official statistics as capital investments or FDI. The supply volume of electricity, gas, and steam, as well as this sector's share in total industrial sales, depend on inflation, state tariff policy, demand inelasticity, and the security situation during wartime, rather than on investment volumes. The operation of the mining and quarrying industry is determined by the availability of mineral deposits, the technical feasibility of their exploitation, and regulatory licensing, while investments in this sector are characterized by long payback periods and do not yield an increase in the share of sales in the year capital expenditures are made. Furthermore, the impact of the investment factor on traditional industrial

sectors during the analyzed period was offset by the predominance of logistical and infrastructural shocks under wartime conditions.

According to the results of the study, the innovation factor proved to be statistically significant only for the food industry: a 1 percentage point (p.p.) increase in the share of innovation-active enterprises contributed to a 1.05 p.p. growth in the share of food manufacturing in total industrial sales. The statistically significant ($R = 0.797$) direct relationship between these variables is explained by the short innovation cycle of the sector, where the rapid adoption of new processing, packaging, and international quality management systems allows for an immediate increase in output with higher value added. According to this model, the share of the food industry in total industrial sales in the Carpathian region was 63.7% dependent on investment, innovation, and labor market factors, while 36.3% depended on other factors not accounted for in the regression analysis, as indicated by the coefficient of determination ($R^2 = 0.637$).

The impact of the share of innovation-active enterprises on changes in the shares of other industrial sectors proved to be statistically insignificant, which overall can be attributed to the relatively low level and local scope of innovation novelty. Specifically, in Lviv oblast in 2020, the number of market-new innovative products introduced stood at 106 units (28.1% of the total number of implemented innovations), whereas in 2024, this number fell to 38 units (18.8% of total implemented innovations). In Zakarpattia oblast, the total number of implemented innovative product types decreased from 46 units in 2022 to 12 in 2023, with no market-new innovations being introduced. Most implemented innovations are process rather than product innovations. Their adoption enhances individual enterprise efficiency but is insufficient to drive structural shifts across industry or expand a specific sector's share in total regional sales. Furthermore, the statistical insignificance of the innovation factor for high-tech machinery manufacturing can be attributed to the operating specifics of this industry: R&D for new products and technologies is conducted abroad by parent companies, while enterprises operating in the Carpathian region perform assembly operations that are not recorded as innovation activity in official statistical reporting. Additional weakening of the innovation factor's impact is also linked to the prevalence of exogenous macroeconomic and wartime logistics shocks during 2014–2024, which significantly hampered the innovation activity of regional enterprises.

As shown in Table 1, the share of industrial employment (Labor1) had an inverse effect on the proportion in total industrial sales of such sectors as food manufacturing (model 2) and manufacture of furniture, other manufacturing, and repair and installation of machinery and equipment (model 11.2). A 1 percentage point (p.p.) increase in the independent variable resulted in a reduction in the respective dependent variables by 1.3 p.p. and 0.19 p.p. At the same time, changes in the share of labor costs in industry (Labor2) positively affected the shares of these sectors in total sales. A 1 p.p. increase in the independent variable contributed to a growth in the dependent variables by 0.34 p.p. (model 2) and 0.064 p.p. (model 11.2), respectively. According to model 12.2, the share of labor costs in industry (Labor2) had an inverse effect on the proportion of electricity, gas, steam, and air conditioning supply in total industrial sales: a 1 p.p. increase in the independent variable led to a 0.97 p.p. decrease in the dependent variable.

The inverse effect of the employment share on the food industry and the furniture and repair service sector is explained by an intersectoral reallocation of the labor force toward large machinery assembly plants, which absorb the primary influx of workforce in the region. Conversely, the positive effect of the share of labor costs on these same sectors aligns with the efficiency wage theory: higher compensation serves as a key prerequisite for retaining skilled workers in the long term and driving labor productivity gains (Kryńska, Kopycińska, 2015). The inverse impact of labor costs on the energy sector's share reflects its capital-intensive nature. At the

same time, expanding the share of the labor-intensive manufacturing sector within the industrial structure naturally reduces the relative weight of infrastructural and resource-intensive industries in total industrial sales.

The econometric evaluation of the factors driving the structural transformation of industry in the Carpathian region was carried out based on a methodological approach involving the modeling of individual sector shares in total industrial sales as a function of changes in domestic consumption, investment, innovation, foreign trade, and employment indicators. Unlike the abstract index of structural shift intensity utilized by S. Shults and O. Lutskiv (2024) in constructing a multifactor regression model for Ukraine's regions in 2013–2021, the dependent variable in this study is defined as the share of a specific sector. This made it possible to identify factors that stimulate the growth of high-tech sectors as well as those that, conversely, hinder the development of high-value-added industries.

The panel regression results for the Carpathian region in 2014–2024 align with the findings obtained by Shults and O. Lutskiv (2024) regarding the positive relationship between structural changes in industry and the innovation factor, as well as the inverse relationship with the labor market factor (industrial employment). By conducting a regression analysis using the shares of industrial sectors within total sales as dependent variables, the study succeeded in pinpointing specific industrial sectors dependent on these factors. Specifically, the shares of the food industry, manufacture of furniture and equipment repair, and electricity, gas, and steam supply were influenced, alongside other factors, by changes in the share of industrial employment and the share of labor costs in industry.

The panel regression results obtained for the Carpathian region regarding the impact of investment and foreign trade factors on structural shifts in industry reveal significant differences from the findings of S. Shults and O. Lutskiv (2024). The authors established an inverse effect on the integral index of structural shifts for both the share of capital investments in industry ($\beta = -0.001$) and the export-to-import ratio ($\beta = -0.559$) across Ukrainian regions during 2013–2021. In contrast, for the industrial complex of the Carpathian region in 2014–2024, a clear direct relationship was identified: an increase in the share of industry in capital investments drove an expansion in the proportion of electrical equipment manufacturing ($\beta = 0.083$), while an increase in the export-to-import ratio positively influenced both the share of electrical equipment manufacturing ($\beta = 3.21$) and the share of electricity, gas, steam, and air conditioning supply ($\beta = 30.52$).

This discrepancy in results can be attributed to several factors: conducting this study specifically for the oblasts of the Carpathian region – which feature a cross-border character of economic activity and are integrated into global value chains – covering data over a longer time horizon, and utilizing a vector of industry shares in total sales as dependent variables. The integral index of structural shifts applied in the work by S. Shults and O. Lutskiv (2024) measures only the general intensity of intersectoral reallocation without taking into account the qualitative direction of such changes. In contrast, using a vector of specific sector shares in this study made it possible to identify the precise directional stimulating effect of foreign trade and investment factors on the primary industrial sectors of the Carpathian region. Unlike the economy of Ukraine's regions overall, where traditional metallurgical and raw-material industries hold significant weight, the Carpathian region is distinguished by a high degree of cross-border integration and a unique investment attraction profile. Furthermore, the analyzed period encompasses 2022–2024, capturing the shocks of the full-scale invasion. During this timeframe, the Carpathian region emerged as a relatively safe relocation hub and a critical energy and logistics node. This significantly reinforced the role of the foreign trade factor and the infrastructure sector (energy supply), transforming traditional intersectoral proportions in favor of the region's energy and export resilience.

Conclusions and Directions for Further Research

The econometric evaluation conducted using panel regressions made it possible to identify the determinants of structural transformation within the industrial complex of the Carpathian region. Foreign trade factors exerted the strongest influence on structural shifts during 2014–2024, positively affecting the growth in the shares of transport equipment manufacturing and electrical equipment manufacturing in total industrial sales. This confirms a high degree of regional integration into European value chains. Furthermore, high-tech imports served as an important factor driving capitalization and sales expansion in the energy sector.

The impact of the investment factor was statistically significant only for the shares of electrical equipment manufacturing and the food industry. The statistical insignificance of this factor for other sectors points to low capital investment volumes and an insufficient concentration of FDI to drive structural shifts in the region.

The innovation factor proved to be statistically significant only for the food industry. The lack of a statistically significant effect of the share of innovation-active enterprises on the proportion of high-tech and medium-high-tech sectors indicates a structural deformation of the innovation process. This situation stems from the fact that most machinery manufacturing enterprises operate under contract assembly schemes and utilize R&D developments from parent companies; consequently, domestic innovations in these sectors remain superficial and, due to a lack of capital investments, fail to reach the critical mass required to expand the sector's share in total output.

The results of evaluating the impact of labor market factors on the structure of industrial production align with the efficiency wage theory. A simple increase in industrial employment is accompanied by an outflow of personnel from traditional sectors in favor of mass assembly operations. In contrast, an increase in the share of labor costs stimulates output growth in the food industry and the furniture and service engineering sector, as higher compensation allows enterprises to attract skilled personnel and boost labor productivity.

The identified impact of domestic consumption factors confirmed the export-oriented model of most industrial sectors in the region, for which domestic demand proved to be statistically insignificant. The impact of consumption is substantial only for locally oriented sectors and conforms to Engel's law: a growing share of food products in wholesale trade turnover indicates a forced shift in consumer demand toward basic needs, which reduces expenditures on furniture and equipment repair, while relatively increasing the share of the energy sector due to the inelasticity of demand for energy.

The practical significance of the econometric evaluation results lies in their application to formulating state strategies and regional development programs. Specifically, the key priorities for driving the structural transformation of industry under martial law and during post-war recovery include: (1) the transition of machine-building enterprises from contract assembly to the development of their own technologies and new products, the creation of dual-purpose technologies, decentralization and technical modernization of energy infrastructure; (2) the introduction of military-political risk insurance instruments, the development of a network of industrial parks, the introduction of benefits for investors in order to increase capital investments in machine-building, as well as support for innovations in the food industry; (3) the implementation of the «effective wage» model, which involves the rejection of competition with cheap labor in favor of proper remuneration; (4) supporting locally oriented manufacturing by involving local enterprises in state and municipal infrastructure reconstruction programs.

Further research into structural shifts in the Carpathian region should focus on building distinct econometric models for Zakarpattia, Ivano-Frankivsk, Lviv,

and Chernivtsi oblasts. These models will allow for forecasting the dynamics of structural changes in the industrial sector and devising targeted regional policy measures to enhance the sectoral structure of industry as a catalyst for accelerated economic growth.

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Бабець І. Г. Економетрична оцінка чинників структурних трансформацій промисловості Карпатського регіону в умовах війни

Мета. Метою статті є ідентифікація та економетричне оцінювання детермінант структурної трансформації промислового комплексу Карпатського регіону в умовах війни.

Методологія. Дослідження базується на оцінюванні панельних регресійних моделей, де залежною змінною є вектор часток окремих галузей у загальному випуску промисловості, а незалежними змінними – показники зовнішньої торгівлі, капітальних інвестицій, ПП, інноваційної активності, ринку праці та внутрішнього споживання.

Результати. Установлено, що зовнішньоторговельні чинники є ключовими рушіями зростання часток транспортного машинобудування та випуску електричного устаткування, що підтверджує істотне залучення цих підприємств регіону до європейських ланцюгів створення доданої вартості. Для постачання електроенергії, газу та пари виявлено значний стимулювальний вплив високотехнологічного імпорту, який забезпечує критичну потребу галузі в сучасному обладнанні для модернізації генерувальних потужностей та відновлення інфраструктури. Виявлено статистичну незначущість інвестицій та інновацій для більшості середньо – та високотехнологічних галузей (окрім харчової), що свідчить про функціонування підприємств на умовах контрактного складання з використанням імпортованих технологій та дефіцит капіталу. Підтверджено дію концепції ефективної заробітної плати: зростання витрат на оплату праці стимулює випуск у харчовій промисловості, виробництві меблів і ремонті обладнання завдяки підвищенню продуктивності. Вплив внутрішнього споживання відповідає закону Енгеля та засвідчує експортну орієнтацію більшості галузей промисловості Карпатського регіону.

Оригінальність. Поглиблення теоретико-методичних засад та емпіричне обґрунтування детермінант структурної трансформації промисловості регіону. Доведено, що аналіз часток окремих галузей є інформативнішим за агрегований індекс, оскільки дає змогу виявити не лише масштаб міжгалузевого перерозподілу, а і якісний напрям розвитку конкретних секторів промисловості.

Практичне значення. Визначено стратегічні напрями промислової політики: перехід від толінгових операцій до власних наукових розробок і технологій подвійного призначення; розбудова індустріальних парків; страхування воєнних ризиків; реалізація моделі ефективної оплати праці та залучення локальних підприємств до відбудови.

Ключові слова: структурна трансформація промисловості, Карпатський регіон, панельна регресія, детермінанти структурних зрушень, експорт, імпорт, інвестиції, інновації, внутрішнє споживання, зайнятість.

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