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Petro Makarenko,
Oleksandr Belov,
Andrii Makarenko,
Lyudmyla Svystun

ASSESSMENT OF HIGH-TECH EXPORT DYNAMICS AND THE IMPACT OF ITS CYCLICALITY ON GDP AND THE COUNTRY'S PRODUCTION RESERVES

The object of this research is the dynamics of high-tech exports and their impact on GDP and production reserves. The instability of high-tech exports can hinder long-term economic growth, particularly in economies where technological sectors play a crucial role in national competitiveness.

To address these issues, the research employs an econometric approach that integrates both linear and cyclical components to analyze the structural dynamics of high-tech exports. As a result, the research identifies two dominant economic cycles, lasting 3.8 and 5.7 years respectively, which significantly influence overall export trends. This is attributed to the nature of high-tech industries, where product innovation cycles, shifts in global demand, and technological progress contribute to periodic fluctuations in export volumes.

The proposed econometric model offers a more accurate assessment of production reserves by identifying periods of economic acceleration and deceleration. This is achieved through the model's ability to isolate cyclical components, enabling strategic adjustments in industrial planning, investment policy, and innovation-driven growth. For instance, based on the identified cycles, companies can better align product launch schedules, reconfigure production capacity during demand slowdowns, and optimize export contract volumes during peak growth periods. Compared to conventional forecasting methods, this approach provides a more comprehensive understanding of high-tech export dynamics, enhancing economic stability and industrial resilience.

The research also holds practical significance. Specifically, the implementation of adaptive budgetary and industrial strategies that are attuned to cyclical dynamics can reduce the risks of overproduction, shortages, or price volatility. In post-war Ukraine, the findings may facilitate the development of strategic policies aimed at the recovery and modernization of the industrial sector. Given limited resources and the urgent need for innovative reconstruction strategies, the proposed model could serve as a foundation for crisis-responsive planning and the rationalization of investments in priority industries.

Keywords: *high-tech, high-tech products, export, production reserves, mathematical modeling, dynamic indicators, cyclicality.*

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1. Introduction

The study of mechanisms for identifying production reserves is becoming increasingly relevant in the context of global competition and innovation-driven development. High-tech manufacturing, encompassing sectors such as computer technology, software, electronics, pharmaceuticals, and other advanced technologies, serves as a crucial driver of economic growth and the formation of competitive advantages. High-tech exports provide significant economic benefits to countries, including revenue growth, job creation, and the attraction of foreign investments. At the same time, the efficiency of the manufacturing sector depends on the economy's ability to adapt to cyclical changes, identify, and utilize internal reserves to ensure sustainable development.

High-tech exports are not only a source of economic growth but also a key indicator of a country's innovation potential [1]. This process necessitates continuous technological advancements, improvements in product quality, and the expansion of research and development activities [2]. A country's participation in international technological exchange facilitates integration into global production chains, enhances the technological level of national industries, and strengthens its position in the global economy. Analyzing the dynamics of high-tech exports allows for an assessment of the current state of industrial development while also identifying potential reserves for expanding production capacity.

This article forms a part of a broader study dedicated to assessing the impact of a country's scientific and technological potential on its economic stability. In particular, it focuses on analyzing the dynamics of high-tech production and exports as a key factor in identifying reserves within the industrial sector. High-tech exports play a vital role in shaping a country's GDP and reflect the development level of its manufacturing base. Since production capacities may not always be fully utilized or may operate at varying levels of efficiency due to cyclical fluctuations in the global economy, their analysis is essential for determining pathways to optimizing production processes.

The development of high-tech and knowledge-intensive industries has been widely explored in academic literature. Previous research has examined the fundamental concepts of scientific and technological potential and its role in national economic development [3]. Other studies have focused on the definition and classification of high-tech industries, identifying the sectors and product categories that fall within this domain [4], as well as the composition and typology of emerging technologies [5].

According to the OECD classification, specific industries have been designated as producers of high-tech goods, providing a framework for assessing their economic significance [6, 7]. The literature further investigates the impact of government policy on high-tech sector development [8], the relationship between innovation and spatial economic patterns [9], and the role of digitalization in shaping high-tech exports [10]. Numerous empirical studies have analyzed the effect of high-tech exports on economic growth across different national contexts, including Israel [11], Japan [12], Turkey [13, 14], the Philippines [15], European Union member states [16], OECD economies [17–19], and Asian country groupings [20].

Additionally, research has explored the interconnection between innovation, export performance, and trade elasticity across industrial sectors [21]. The relationship between medium- and high-tech exports at the European level and key determinants of innovation has also been examined [22]. Studies on the United Kingdom's high-tech enterprises highlight the influence of exports on subsequent innovation performance [23]. Furthermore, scholars have demonstrated that international high-tech exports play a critical role in advancing frontier technologies, particularly in emerging economies [24].

To study cyclical phenomena in the economy, researchers employ various methods, including the vector error correction model (VECM) [25], the dynamic factor model with time-varying loadings and stochastic volatility [26], the multiple scale method [27], a novel application of geometric Brownian motion [28], the high-dimensional multi-level factor model [29], the VAR model [30], the Beveridge-Nelson decomposition [31], nonlinear Harrodian instability [32], and the dynamic stochastic general equilibrium (DSGE) model [33, 34].

However, the study of cyclicality in high-tech export dynamics remains an open question. Examining the cyclicality of high-tech export dynamics can reveal specific trends and patterns that influence a country's economic development. For instance, it may be found that the cyclicality of high-tech exports is linked to changes in global demand for innovative products or the periodic nature of global technological trends. Periodic fluctuations in demand for innovative products may indicate the need for adjustments in production strategies and resource management. Moreover, analyzing export cyclicality can help identify potential risks associated with demand fluctuations and technological changes that impact the efficiency of production resource utilization. Recognizing such patterns can support the development of effective risk management strategies, production diversification, and the resilience of the high-tech sector.

Thus, further research into the cyclicality of high-tech export dynamics is essential for uncovering hidden production reserves, formulating effective economic strategies, and ensuring the stable development of the industrial sector.

The aim of this research is to assess the dynamics of high-tech exports and examine the impact of their cyclical nature on GDP growth and the identification of the country's production reserves. The proposed approach focuses on evaluating the impact of cyclical components on high-tech exports and their interrelation with industrial production and GDP. The findings will contribute to the formation of a scientific foundation for national strategies aimed at enhancing the effectiveness of government regulation in the fields of innovation and scientific and technological development.

2. Materials and Methods

The object of this research is the dynamics of high-tech exports and their impact on GDP and production reserves. One of the most critical challenges in this area is the cyclical fluctuations in high-tech exports, which can lead to inefficiencies in resource allocation and production planning. To achieve the aim, the research employs the correlation-regression analysis method, incorporating the cyclical component [35, 36]. The authors have selected several types of models for analysis (M_1–M_5) in order of increasing complexity: a simple linear model, an accelerated growth model, a linear model with a cycle, an accelerated growth model with a single cycle, and an accelerated growth model with two cycles (Table 1).

The term "accelerated development" refers to an acceleration of motion, commonly used in natural sciences, and mathematically represented as the parameter $c \cdot x^2$, where the acceleration equals 2 c.

The economic characterization of the regression equation parameters for models M_1–M_5 is presented in Table 2.

Table 1

Types of econometric models for regression analysis of high-tech export dynamics

Model	Formula	Name
M_1	$y = a + b \cdot x$	Linear
M_2	$y = a + b \cdot x + c \cdot x^2$	Linear with acceleration
M_3	$y = a + b \cdot x + c \cdot \sin(d \cdot x + e)$	Linear with a cycle
M_4	$y = a + b \cdot x + c \cdot x^2 + d \cdot \sin(e \cdot x + f)$	Linear with acceleration and a cycle
M_5	$y = a + b \cdot x + c \cdot x^2 + d \cdot \sin(e \cdot x + f) + g \cdot \sin(h \cdot x + i)$	Linear with acceleration and two cycles

Note: *a, b, c, d, e, f, j, i* – parameters, which economic characteristics will be presented in Table 2

Table 2

Economic characterization of the regression equation parameters

Model parameters					Economic characteristics	Unit of measurement
M_1	M_2	M_3	M_4	M_5	–	–
1	2	3	4	5	6	7
The linear component of the model – determines the linear trend of the dynamics of the studied indicator						
a	*a*	*a*	*a*	*a*	Initial level of the studied indicator	USD 2010
b	*b*	*b*	*b*	*b*	Average rate of change in the dynamics of the studied indicator	USD 2010/year

Continuation of Table 2

1	2	3	4	5	6	7
Non-linear components of the model:						
1. Acceleration						
–	c	–	c	c	The average acceleration of changes in the dynamics of the studied indicator	USD 2010/year^2
2. Cycles						
–	–	$c\cdot\sin(d\cdot x+e)$	$d\cdot\sin(e\cdot x+f)$	$d\cdot\sin(e\cdot x+f)$	First harmonic	USD 2010
–	–	c	d	d	The amplitude of cyclical fluctuations – the maximum deviation	USD 2010
–	–	d	e	e	Cyclical frequency	Radian
–	–	e	f	f	Initial phase of the cycle	Radian
–	–	ν_1	ν_1	ν_1	Oscillation frequency	Times
–	–	T_1	T_1	T_1	Period of oscillation	Year
–	–	–	–	$g\cdot\sin(h\cdot x+i)$	Second harmonic	–
–	–	–	–	g	The amplitude of cyclical fluctuations – the maximum deviation	USD 2010
–	–	–	–	h	Cyclical frequency	Radian
–	–	–	–	i	Initial phase of the cycle	Radian
–	–	–	–	η_2	Oscillation frequency	Times
–	–	–	–	T_2	Period of oscillation	Year

The research algorithm will include the following stages:

1. Finding the parameters of the selected types of econometric models and comparing their statistical characteristics in order to assess the dynamics of high-tech product exports.
2. Comparing the obtained results with each other and with actual data.
3. Separately comparing the parameters of the cyclical component of the obtained models.
4. Selecting the best econometric model to assess the dynamics of high-tech product exports, its analysis, and economic interpretation.
5. Identifying the share of the cyclical component's impact in this model.
6. Steps 1–5 for high-tech exports (% of total manufactured exports).
7. Steps 1–5 for high-tech exports (% of GDP).
8. Steps 1–5 for GDP.
9. Steps 1–5 for the export of manufacturing products.
10. Assessing the impact of cyclical components on the dynamics of these indicators and their relationships.

Selection of Initial Data: This research is based on the example of Canada. Canada is an economically developed country that is part of the G7 group of nations. Canada ranked 21st among 217 countries in terms of high-tech exports in 2020, with its contribution to the global high-tech export market being 0.90%.

Since in September 2019, the World Development Indicators database was updated from SITC Rev. 3 to SITC Rev. 4, data on the World Bank website [37] is available only from 2007 onwards. This source also contains the indicator for the share of high-tech product exports in total manufactured exports (High-technology exports (% of manufactured exports)). The same website provides data on GDP dynamics for the same period. To adjust the data for inflation, the US inflation statistics website [38] was used to convert them to 2010 prices. The dynamics of the share of high-tech product exports in GDP was calculated by the author based on the above data.

3. Results and Discussion

3.1. Analysis and assessment of the dynamics of high-tech exports

Selection of the econometric model. The parameters of the econometric models, according to Table 1, were obtained using the cross-platform solution for curve fitting and data analysis, CurveExpert 1.38, and are presented in Table 3.

Table 3

Calculation of the parameters of econometric models assessing the dynamics of Canada's high-tech exports from 2007 to 2020

Statistical metrics	M_1	M_2	M_3	M_4	M_5
Coefficient data	a = 30.9448	a = 30.7817	a = 30.8356	a = 28.7696	a = 28.2289
	b = – 0.5020	b = – 0.4408	b = – 0.5174	b = 0.2479	b = 0.3805
	–	c = – 0.0041	c = 2.7046	c = – 0.0515	c = – 0.0588
	–	–	d = 1.0878	d = 3.0204	d = 1.0521
	–	–	e = 0.5969	e = 1.0798	e = 1.6660
	–	–	–	f = 0.5385	f = – 1.3482
	–	–	–	–	g = 2.9320
	–	–	–	–	h = 1.1009
	–	–	–	–	i = 0.3782
Standard error	2.4046	2.5106	1.4675190	1.2874824	1.1728539
Correlation coefficient	0.6726	0.6729	0.9203464	0.9462283	0.9724818
Comments	–	–	The fit converged to a tolerance of 0.001 in 5 iterations. No weighting used	The fit converged to a tolerance of 0.001 in 6 iterations. No weighting used	The fit converged to a tolerance of 0.001 in 49 iterations. No weighting used

As is seen, the correlation coefficient increases with the complexity of the model. The simple linear model (M_1) has a correlation coefficient of 0.67, while the linear model with acceleration and accounting for two harmonics (M_5) has a correlation coefficient of 0.97 (Table 3).

It should be noted that models M_4 and M_5, which account for cyclical components, yield the highest correlation coefficient values, indicating the presence of oscillatory processes in the dynamics of high-tech exports in the country under consideration.

This also suggests that the dynamics of Canada's high-tech exports from 2007 to 2020 were characterized by both a linear trend and the presence of acceleration (in this case, negative, indicating a slowdown in development) as well as a cyclical component.

Analysis of the obtained results: Table 4 allows to assess the forecast values for high-tech exports for the next three years, up to 2023. Model M_5 predicts a decrease in high-tech export volumes in 2023 to 19.429 billion USD (2010 prices).

The comparison of the obtained models and forecasts is presented in Fig. 1, where the actual data are marked with "U", and the trends of the calculated models are shown by lines. Considering the correlation coefficients, for further analysis, it is possible to choose the model with the highest value – M_5. In economic terms, this means that two cycles are active.

Comparison of the parameters of the cyclic component of the obtained models. Comparison of the cyclic characteristics in models M_3–M_5 is given in Table 5.

Table 4

Forecast of the dynamics of high-tech product exports from Canada according to the obtained models

No.	Year	M_1	M_2	M_3	M_4	M_5	Y
1	2007	30.443	30.337	33.005	31.983	31.799	31.856
2	2008	29.941	29.884	30.777	30.355	31.279	31.411
3	2009	29.439	29.423	27.503	27.255	26.823	26.027
4	2010	28.937	28.953	26.136	25.949	25.019	26.566
5	2011	28.435	28.476	27.586	27.699	28.195	26.708
6	2012	27.933	27.990	29.746	30.427	31.023	31.604
7	2013	27.431	27.496	29.747	30.913	30.049	30.264
8	2014	26.929	26.994	27.035	28.198	27.622	26.869
9	2015	26.427	26.484	23.960	24.596	25.593	26.171
10	2016	25.925	25.966	23.261	23.252	23.851	23.788
11	2017	25.423	25.439	25.133	24.814	24.067	23.951
12	2018	24.921	24.905	27.016	26.750	26.616	26.592
13	2019	24.419	24.362	26.340	26.023	26.779	27.234
14	2020	23.917	23.811	23.274	22.304	21.804	21.476
15	2021	23.415	23.252	20.548	18.315	16.943	22.987
16	2022	22.913	22.685	20.528	16.957	17.232	23.059
17	2023	22.411	22.109	22.681	18.239	19.429	25.233
18	2024	21.909	21.526	24.146	19.273	18.510	–
19	2025	21.407	20.934	22.801	17.321	15.169	–

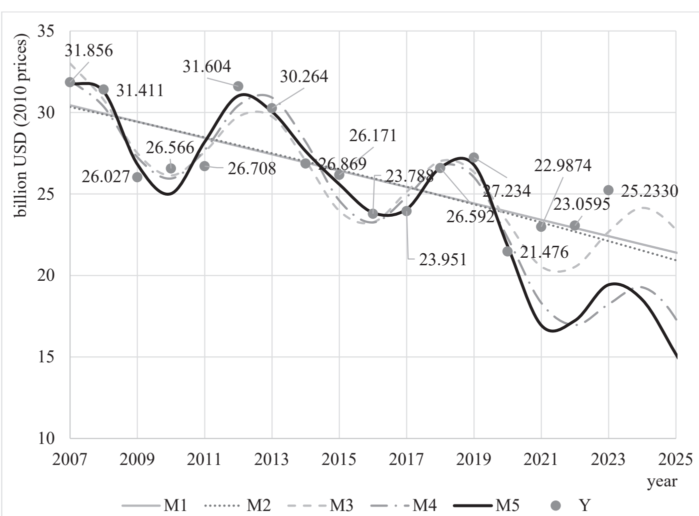

Fig. 1. Comparison of the obtained models of the dynamics of exports of high-tech products of Canada until 2025

Table 5

Characteristics of the cyclical component of the studied models (M_3–M_5)

Parameter	M_3	M_4	M_5 (1st)	M_5 (2nd)
Angular frequency, radians	1.088	1.080	1.666	1.101
Frequency, times in year	0.173	0.172	0.265	0.175
Period, years	5.776	5.819	3.771	5.707
Phase, radians	0.597	0.539	– 1.348	0.378
Offset, period fraction	0.095	0.086	– 0.215	0.060
Offset, years	0.549	0.499	– 0.809	0.344
Offset, months	6.6	6.0	– 9.7	4.1
Amplitude, billion USD 2010	2.705	3.020	1.052	2.932

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From the results of the table, it is possible to observe that in some cases, the calculations yielded negative values for the cyclical frequency and period of oscillation. At this stage of the research, to determine the economic meaning of the parameters of the obtained models, it is possible to take the period of oscillation by its absolute value.

The models indicate the presence of oscillations in the dynamics of high-tech exports from Canada, but with different periods and initial shifts in relation to the starting point (year) of observation.

Selection of an econometric model for evaluating the dynamics of high-tech product exports, its analysis, and economic interpretation. Based on the calculations, the model that best describes the dynamics of high-tech product exports from Canada in 2007–2020 is model M_5.

To analyze how the cyclical component affects the dynamics of high-tech exports, it is necessary to calculate the impact of each component of model M_5 in absolute (Table 6) and relative (Table 7) values, as well as the error (deviation) of the calculated values from the actual data.

In Table 7, parameters such as the mean value, median, maximum, and minimum for each component have also been calculated. It should be noted that, considering the nature of the cyclical component, the values of the mean and median will be close to zero, providing no information about their impact. At the same time, the maximum and minimum values indicate the range of influence exerted by the cyclical component on the dynamics of high-tech exports.

Table 6

Analysis of the structure of model M_5 for the dynamics of high-tech product exports in billion USD (2010 prices)

Year	a	bx	$c\cdot x^2$	$d\cdot\sin(e\cdot x+f)$	$g\cdot\sin(h\cdot x+i)$	Y_{teor}	Y	Δ
2007	28.229	0.380	– 0.059	0.329	2.920	31.799	31.856	0.057
2008	28.229	0.761	– 0.235	0.964	1.561	31.279	31.411	0.132
2009	28.229	1.141	– 0.529	– 0.512	– 1.506	26.823	26.027	– 0.796
2010	28.229	1.522	– 0.941	– 0.866	– 2.925	25.019	26.566	1.548
2011	28.229	1.902	– 1.470	0.677	– 1.143	28.195	26.708	– 1.487
2012	28.229	2.283	– 2.117	0.738	1.890	31.023	31.604	0.582
2013	28.229	2.663	– 2.881	– 0.817	2.854	30.049	30.264	0.215
2014	28.229	3.044	– 3.763	– 0.583	0.695	27.622	26.869	– 0.752
2015	28.229	3.424	– 4.762	0.928	– 2.225	25.593	26.171	0.578
2016	28.229	3.805	– 5.879	0.406	– 2.710	23.851	23.788	– 0.062
2017	28.229	4.185	– 7.114	– 1.005	– 0.228	24.067	23.951	– 0.116
2018	28.229	4.565	– 8.466	– 0.215	2.503	26.616	26.592	– 0.023
2019	28.229	4.946	– 9.936	1.046	2.495	26.779	27.234	0.455
2020	28.229	5.326	– 11.524	0.016	– 0.244	21.804	21.476	– 0.328
2021	28.229	5.707	– 13.229	– 1.049	– 2.715	16.943	22.987	6.045
2022	28.229	6.087	– 15.051	0.183	– 2.215	17.232	23.059	5.827
2023	28.229	6.468	– 16.992	1.014	0.709	19.429	25.233	5.804
2024	28.229	6.848	– 19.049	– 0.376	2.858	18.510	–	–
2025	28.229	7.229	– 21.225	– 0.943	1.878	15.169	–	–

Table 7

Analysis of the structure of model M_5 for the dynamics of high-tech product exports (%)

Year	a	bx	$c\cdot x^2$	$d\cdot\sin(e\cdot x+f)$	$g\cdot\sin(h\cdot x+i)$	Y_{teor}	Y	Δ
2007	88.6%	1.2%	– 0.2%	1.0%	9.2%	99.8%	100.0%	0.2%
2008	89.9%	2.4%	– 0.7%	3.1%	5.0%	99.6%	100.0%	0.4%
2009	108.5%	4.4%	– 2.0%	– 2.0%	– 5.8%	103.1%	100.0%	– 3.1%
2010	106.3%	5.7%	– 3.5%	– 3.3%	– 11.0%	94.2%	100.0%	5.8%
2011	105.7%	7.1%	– 5.5%	2.5%	– 4.3%	105.6%	100.0%	– 5.6%
2012	89.3%	7.2%	– 6.7%	2.3%	6.0%	98.2%	100.0%	1.8%
2013	93.3%	8.8%	– 9.5%	– 2.7%	9.4%	99.3%	100.0%	0.7%
2014	105.1%	11.3%	– 14.0%	– 2.2%	2.6%	102.8%	100.0%	– 2.8%
2015	107.9%	13.1%	– 18.2%	3.5%	– 8.5%	97.8%	100.0%	2.2%
2016	118.7%	16.0%	– 24.7%	1.7%	– 11.4%	100.3%	100.0%	– 0.3%
2017	117.9%	17.5%	– 29.7%	– 4.2%	– 1.0%	100.5%	100.0%	– 0.5%
2018	106.2%	17.2%	– 31.8%	– 0.8%	9.4%	100.1%	100.0%	– 0.1%
2019	103.7%	18.2%	– 36.5%	3.8%	9.2%	98.3%	100.0%	1.7%
2020	131.4%	24.8%	– 53.7%	0.1%	– 1.1%	101.5%	100.0%	– 1.5%
Average	105.2%	11.1%	– 16.9%	0.2%	0.5%	100.1%	100.0%	– 0.1%
Me	105.9%	10.1%	– 11.8%	0.6%	0.8%	100.0%	100.0%	0.0%
Max	131.4%	24.8%	– 0.2%	3.8%	9.4%	105.6%	100.0%	5.8%
Min	88.6%	1.2%	– 53.7%	– 4.2%	– 11.4%	94.2%	100.0%	– 5.6%

In the case of Canada, the following observation can be made: the cyclical component significantly influences the overall dynamics of high-tech exports in the country. Specifically, the first harmonic has an impact ranging from – 4.2% to + 3.8%, but in the near future, its negative influence will increase. The negative sign indicates a decrease in high-tech export volumes. The second harmonic exerts a greater influence, ranging from – 11.7% to + 9.4%, and its positive impact is expected to increase in the near future. In other words, the harmonics counterbalance each other's effects throughout the entire observed period (Fig. 2).

Table 7 allows to assess the impact of each component of Model 5 on the dynamics of Canada's high-tech exports. It also enables comparison with the error, which describes other random factors. Their influence fluctuates from – 5.6% to + 5.8%. The critical values (maximum and minimum) of the cyclical component exceed the critical values of random factors. The dynamics of Canada's high-tech exports can be characterized as follows:

1) there is a stable baseline (*a*), which is an important positive component. This baseline is likely formed through long-term contracts with business partners;

2) there is a constant growth rate, which impact on export dynamics increases linearly. These could be business plans or projects related to expanding exports from the country annually, introducing new types of products in the high-tech sector;

3) there are several factors that slow down the export dynamics, and their influence grows exponentially. These factors may include a decline in the qualifications of the workforce, constant market changes, technological challenges, administrative restrictions, increased competition, and market saturation;

4) cyclical factors are similar to those mentioned in point 3, but they develop in cycles;

5) random factors include all other predominantly random events, such as accidents, logistics errors, production issues, financial flows, psychological factors, and other unpredictable events.

3.2. Analysis of the impact of the cyclical component of high-tech exports according to the selected regression model

Based on the data from Tables 8 and 9, the following observations can be made. The base level of high-tech exports is 28.230 billion USD in 2010 prices, which fluctuates from 88.61% to 131.44% of its dynamics over the studied period. The linear speed of high-tech exports ranges from 0.380 to 5.326 billion USD in 2010 prices, accounting for 1.19% to 24.80% of its dynamics over the studied period. The acceleration of high-tech exports ranges from – 11.524 to – 0.059 billion USD in 2010 prices, corresponding to – 53.66% to – 0.18% of its dynamics over the studied period. The linear component of the dynamics $\left(y=a+b\cdot x\right)$ of high-tech exports ranges from 28.609 to 33.555 billion USD in 2010 prices, contributing 89.81% to 156.24% of its dynamics over the studied period. Along with the acceleration, the linear component $\left(y=a+b\cdot x+c\cdot x^2\right)$ of high-tech exports ranges from 22.032 to 28.841 billion USD in 2010 prices, accounting for 85.33% to 110.81% of its dynamics over the studied period.

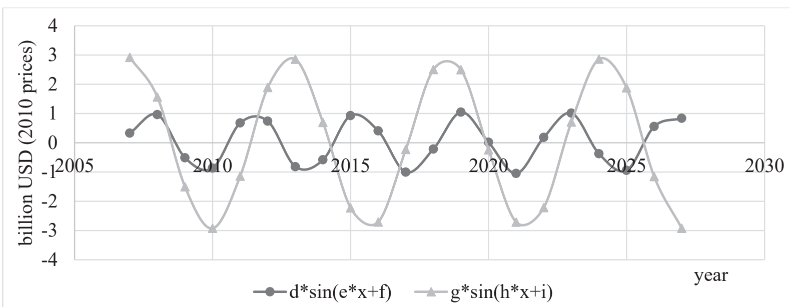

Fig. 2. Comparison of cyclical components of high-technology exports dynamics with each other

Table 8

Analysis of the impact of different components on the dynamics of high-tech exports in billions of USD at 2010 prices

Year	Line	Nonline	Cycle	Line + Nonline
2007	28.6094	– 0.0588	3.2484	28.5506
2008	28.9898	– 0.2352	2.5249	28.7546
2009	29.3703	– 0.5291	– 2.0179	28.8411
2010	29.7507	– 0.9407	– 3.7912	28.8100
2011	30.1312	– 1.4699	– 0.4661	28.6613
2012	30.5116	– 2.1166	2.6279	28.3950
2013	30.8921	– 2.8809	2.0374	28.0112
2014	31.2726	– 3.7628	0.1121	27.5097
2015	31.6530	– 4.7623	– 1.2978	26.8907
2016	32.0335	– 5.8794	– 2.3035	26.1540
2017	32.4139	– 7.1141	– 1.2332	25.2998
2018	32.7944	– 8.4664	2.2876	24.3280
2019	33.1748	– 9.9362	3.5405	23.2386
2020	33.5553	– 11.5237	– 0.2272	22.0316
2021	33.9358	– 13.2287	– 3.7643	20.7070
2022	34.3162	– 15.0513	– 2.0325	19.2649
2023	34.6967	– 16.9915	1.7234	17.7051
2024	35.0771	– 19.0493	2.4821	16.0278
2025	35.4576	– 21.2247	0.9358	14.2328

Table 9

Structure of the impact of different components on the dynamics of high-tech exports

Year	Line	Acceleration	Cycle	Line + Acceleration
2007	89.8%	– 0.2%	10.2%	89.6%
2008	92.3%	– 0.7%	8.0%	91.5%
2009	112.8%	– 2.0%	– 7.8%	110.8%
2010	112.0%	– 3.5%	– 14.3%	108.4%
2011	112.8%	– 5.5%	– 1.7%	107.3%
2012	96.5%	– 6.7%	8.3%	89.8%
2013	102.1%	– 9.5%	6.7%	92.6%
2014	116.4%	– 14.0%	0.4%	102.4%
2015	120.9%	– 18.2%	– 5.0%	102.8%
2016	134.7%	– 24.7%	– 9.7%	109.9%
2017	135.3%	– 29.7%	– 5.1%	105.6%
2018	123.3%	– 31.8%	8.6%	91.5%
2019	121.8%	– 36.5%	13.0%	85.3%
2020	156.2%	– 53.7%	– 1.1%	102.6%
Min	89.8%	– 53.7%	– 14.3%	85.3%
Max	156.2%	– 0.2%	13.0%	110.8%

The first harmonic of high-tech exports ranges from –1.005 to 1.046 billion USD in 2010 prices, contributing from –4.20% to 3.84% of its dynamics over the studied period.

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The second harmonic of high-tech exports ranges from –2.925 to 2.920 billion USD in 2010 prices, corresponding to –11.39% to 9.43% of its dynamics over the studied period. The total impact of the cyclical component on high-tech exports ranges from –3.791 to 3.541 billion USD in 2010 prices, accounting for –14.27% to 13.00% of its dynamics over the studied period. The influence of other factors on high-tech exports ranges from –1.487 to 1.548 billion USD in 2010 prices, contributing from –5.57% to 5.83% of its dynamics over the studied period.

Analysis and evaluation of the dynamics of the share of high-tech exports in total manufacturing exports. Next, let's model the dynamics of high-tech exports in relation to the total manufacturing exports of Canada during this period. The overall results are presented in Tables 10 and 11 and in Fig. 3.

Table 10

Calculation of econometric model parameters evaluating the dynamics of the share of high-tech exports in Canada's manufacturing exports from 2007 to 2020

Statistical metrics	M_1	M_2	M_3	M_4	M_5
Coefficient data	a = 15.5771	a = 16.1140	a = 15.7228	a = 16.5447	a = 17.2855
	b = – 0.0382	b = – 0.2395	b = – 0.0537	b = – 0.3659	b = – 0.5530
	–	c = 0.0134	c = 0.7736	c = 0.0212	c = 0.0310
	–	–	d = 1.9068	d = 0.8335	d = 2.5004
	–	–	e = – 10.4940	e = – 1.9424	e = – 1.7054
	–	–	–	f = 20.0158	f = 24.6052
	–	–	–	–	g = 2.4296
	–	–	–	–	h = – 1.5912
	–	–	–	–	i = 26.7247
Standard error	0.9584	0.9769	0.8803196	0.8535604	0.5872191
Correlation coefficient	0.1708	0.2746	0.6210569	0.6976100	0.9209502
Comments	–	–	The fit converged to a tolerance of 0.001 in 21 iterations. No weighting used	The fit converged to a tolerance of 0.001 in 27 iterations. No weighting used	The fit converged to a tolerance of 0.001 in 62 iterations. No weighting used

Table 11

Structure of the impact of components on the dynamics of the share of high-tech exports in Canada's manufacturing exports and the forecast

Year	Line	Nonline	Cycle	Line + Nonline
2007	16.7326	0.0310	– 1.9701	16.7636
2008	16.1796	0.1240	– 0.6413	16.3036
2009	15.6266	0.2791	1.5893	15.9057
2010	15.0736	0.4962	0.2369	15.5698
2011	14.5207	0.7753	– 1.1009	15.2959
2012	13.9677	1.1164	0.0139	15.0841
2013	13.4147	1.5195	0.5470	14.9342
2014	12.8617	1.9847	– 0.0938	14.8464
2015	12.3088	2.5118	0.0255	14.8206
2016	11.7558	3.1010	– 0.0023	14.8568
2017	11.2028	3.7522	– 0.5687	14.9551
2018	10.6498	4.4655	0.2662	15.1153
2019	10.0969	5.2407	1.0365	15.3376
2020	9.5439	6.0780	– 0.6776	15.6219
2021	8.9909	6.9773	– 1.3885	15.9682
2022	8.4380	7.9386	1.2052	16.3766
2023	7.8850	8.9620	1.5926	16.8469
2024	7.3320	10.0473	– 1.8090	17.3793
2025	6.7790	11.1947	– 1.6276	17.9737

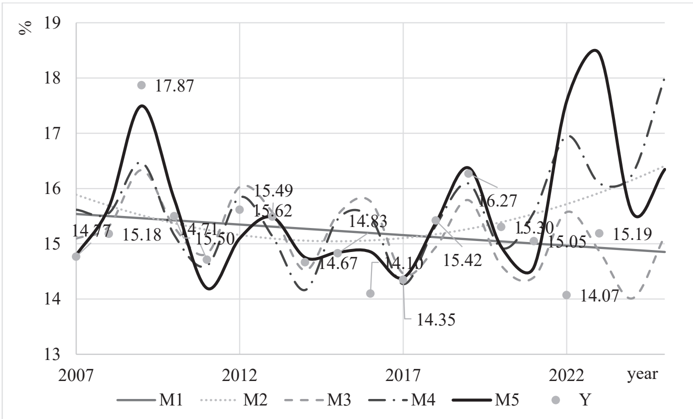

Fig. 3. Comparison of the obtained models and the forecast of the dynamics of the share of high-tech exports in Canada's manufacturing exports until 2025

The total impact of the cyclical component on the share of high-tech exports in total manufacturing exports ranges from – 1.970% to 1.592%, representing a change in its dynamics from – 13.34% to 8.89% over the study period. The impact of other factors ranges from – 0.756% to 0.517%, representing a change in dynamics from – 5.36% to 3.51% over the same period. Since the speed (*b*) is less than zero, a decrease in the dynamics of the share of high-tech exports in total manufacturing exports is observed. Given that acceleration is greater than zero, there is an acceleration in the dynamics of the studied indicator.

The amplitude of the 1st harmonic is greater than zero, indicating an initial positive impact of the cyclical factor on the dynamics under study. It will turn negative after 0.25 periods, i. e., after – 0.92 years, and will be most negative after 0.5 periods, i. e., after – 1.84 years.

The amplitude of the 2nd harmonic is greater than zero, indicating an initial positive impact of the cyclical factor on the studied dynamics. It will turn negative after 0.25 periods, i. e., after – 0.99 years, and will be most negative after 0.5 periods, i. e., after – 1.97 years.

The initial phase of the 1st harmonic is greater than zero, meaning that the onset of the cyclical component occurs with a delay of – 14.43 years, or, equivalently, – 173.14 months after the start of the observation. The initial phase of the 2nd harmonic is greater than zero, meaning that the onset of the cyclical component occurs with a delay of – 16.80 years, or – 201.55 months after the start of the observation.

Stages 6–9 from the established algorithm were performed using the same methodology, and the overall results are summarized in Table 12, which will be analyzed in detail in the next section of this article.

3.3. Assessment of the impact of cyclical components on the dynamics of these indicators and their interrelationship

Let's compare the cyclical components of high-tech export dynamics, the share of high-tech exports in total manufacturing exports, the share of high-tech exports in the country's GDP, and the GDP and manufacturing export values themselves (Table 12).

What factors can create cyclical impact? Inflation has been excluded (calculations are made in 2010 prices), as well as seasonal fluctuations (data are taken annually rather than quarterly). The fluctuations in high-tech exports represent a combination of sectors – aerospace, instrumentation, information technology, and pharmaceuticals – which are the most science-intensive industries. These cycles can reflect, on the one hand, the life cycle of the creation, implementation, and global market entry of new science-intensive products, and, on the other hand, the market conditions and demand for these products from national producers.

It can be noted that in the dynamics of high-tech exports, there is a moderate impact of cyclical components, with the total weighted effect ranging from – 14.27% to 13.00%. These cycles have periods of fluctuation of 3.8 and 5.7 years, indicating the impact of short-term and medium-term processes. The initial phases of the fluctuations are – 0.81 and 0.34 years, meaning the fluctuation component of the 1st harmonic began to influence the dynamics of high-tech exports around 2006, while the 2nd harmonic started in 2007.

The next indicator is the share of high-tech exports in total manufacturing exports of the country. Here, it is possible to observe a large degree of impact from the cyclical components on the dynamics of the indicator: from –17.04% to 16.93% (1st harmonic), and from – 16.95% to 16.40% (2nd harmonic). However, when combined, these effects dampen the cycles by 1.5 times, resulting in an impact ranging from – 13.34% to 8.89% on the overall dynamics. The periods of fluctuation for both harmonics were 3.68 and 3.95 years. Thus, the share of high-tech exports in total manufacturing exports is less susceptible to cyclical fluctuations than its absolute change.

Table 12

Cyclical component impact analysis on the studied indicators dynamics

Parameter	High-technology exports (constant 2010 billion USD)	High-technology exports (% of manufactured exports)	High-technology exports (% of GDP)	GDP (constant 2010 billion USD)	Manufactured exports (constant 2010 billion USD)
1	2	3	4	5	6
1st harmonica					
Angular frequency, radians	1.67	1.71	0.44	14.65	0.944
Frequency, times in year	0.27	0.27	0.07	2.33	0.150
Period, years	3.77	3.68	14.14	0.43	6.656
Phase, radians	– 1.35	24.61	21.57	73.18	– 28.981
Offset, period fraction	– 0.21	3.92	3.43	11.65	– 4.612
Offset, years	– 0.81	– 14.43	– 48.54	4.99	– 30.702
Offset, months	– 9.71	– 173.14	– 582.53	59.94	– 368.428
Amplitude	1.05	2.50	– 0.20	57.91	185.018
Effect on dynamics, max, %	3.84%	16.93%	11.70%	4.05%	99.85%
Effect on dynamics, min, %	– 4.20%	– 17.04%	– 10.70%	– 3.22%	– 107.98%
2nd harmonica					
Angular frequency, radians	1.10	1.59	1.96	24.20	0.923

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Continuation of Table 12

1	2	3	4	5	6
Frequency, times in year	0.18	0.25	0.31	3.85	0.147
Period, years	5.71	3.95	3.21	0.26	6.805
Phase, radians	0.38	26.72	– 13.69	– 58.54	37.219
Offset, period fraction	0.06	4.25	– 2.18	– 9.32	5.924
Offset, years	0.34	– 16.80	– 6.99	– 2.42	40.312
Offset, months	4.12	– 201.55	– 83.89	– 29.03	483.741
Amplitude	2.93	2.43	– 0.12	– 139.04	177.086
Effect on dynamics, max, %	9.43%	16.40%	6.67%	9.36%	100.31%
Effect on dynamics, min, %	– 11.39%	– 16.95%	– 7.62%	– 9.94%	– 94.76%
The total effect of the cyclical component on the dynamics of the indicator, max, %	13.27%	33.33%	18.37%	13.40%	200.16%
The total effect of the cyclical component on the dynamics of the indicator, min, %	– 15.59%	– 33.99%	– 18.32%	– 13.16%	– 202.74%
Total weighted effect of the cyclical component on the dynamics of the indicator, max, %	13.00%	8.89%	15.60%	10.10%	15.03%
Total weighted effect of the cyclical component on the dynamics of the indicator, min, %	– 14.27%	– 13.34%	– 13.15%	– 13.16%	– 16.52%

If to examine the dynamics of the share of high-tech exports in the country's GDP (also adjusted for inflation by recalculating to 2010 constant prices), it is possible to find that, in relation to GDP, oscillatory phenomena had 1.1 times greater influence than on the dynamics of absolute values, ranging from –13.15% to 15.60%. The harmonic fluctuations had different periods of 14.1 and 3.2 years, with oscillation amplitudes of –0.2 and –0.1, indicating a stronger influence of the first harmonic compared to the second.

Overall industrial exports are also subject to cyclical fluctuations, as is high-tech export. The negative impact of the cyclical component on industrial exports was 0.86 times lower, reaching – 16.52%, while the positive impact was 1.16 times higher, reaching 15.03%.

It should be noted that at the end of 2024, the World Bank updated its data on Canada's high-tech exports up to 2023 [39], allowing to compare the obtained forecast data with actual figures. The actual high-tech export at 2010 prices amounted to 22.87 billion USD in 2021, while according to the M5 model, it was expected to be 16.95 billion USD, meaning the forecast error was 34.9%. A similar error was observed for 2022 and 2023. This can be explained by the extraordinary circumstances of 2020–2023 – the COVID-19 pandemic and government measures to combat it, which directly resulted in unexpectedly high revenues for pharmaceutical companies (one of the key components of high-tech exports) that received excess profits. Additionally, unprecedented large-scale financial injections into the US economy indirectly influenced Canada's entire export sector, as nearly 80% of its exports are directed to the US.

During 2021–2023, there was a sharp increase in demand for pharmaceutical products (vaccines, medical equipment) as well as digital technologies (IT services, semiconductors). This could have led to an anomalous growth in exports not observed in the previous 15-year period. It also triggered large-scale financial stimulus programmes, namely economic support initiatives in the US, Canada, the EU, and other countries, which led to increased demand for high-tech products. For example, investments in digital transformation and "green" technologies influenced the export structure. Moreover, several additional factors should be considered: during 2021–2023, the adoption of artificial intelligence, automation, and digital technologies accelerated, which could have influenced export dynamics faster than anticipated; the escalation of trade wars, specifically US-imposed restrictions on high-tech exports to China, may have redirected trade flows, altering Canada's export dynamics; the global semiconductor shortage (2021–2022) caused fluctuations in electronics and automobile production.

At the same time, the error between the actual and forecasted share of high-tech exports in Canada's total industrial exports was only 2.7%. This, in our opinion, first confirms the adequacy of the proposed model, and second, demonstrates that new external factors (the pandemic, trade wars, rapid AI development) and internal factors (significant financial injections into the economies of importing countries) may partially alter expected trends.

Practical Relevance. The findings of this research offer significant insights for policymakers, economists, and industry professionals engaged in high-tech sector development and economic planning. The proposed econometric model, integrating both linear and cyclical components, enhances the accuracy of high-tech export trend forecasting, enabling enterprises and governments to better adapt to economic fluctuations.

The practical applications of the research results are multifaceted. First, they facilitate the optimization of production strategies, allowing enterprises to align their production capacity with anticipated market demand based on cyclical trends. For example, based on the identified cycles, it is possible to adapt product launch schedules, reconfigure production capacities during phases of declining demand, and optimize the volume of export contracts during periods of peak growth. Second, the findings contribute to the improvement of public policies, supporting the development of targeted assistance programs for high-tech industries during economic downturns and reinforcing incentive mechanisms during periods of growth. Third, the research provides valuable insights for investment decision-making, enabling investors and financial institutions to assess risks and opportunities within the high-tech sector with greater precision.

A particularly crucial application pertains to Ukraine's post-war economic recovery. Understanding cyclicality in high-tech exports offers a foundation for formulating effective industrial policies, fostering economic resilience, and stimulating recovery efforts. Under conditions of resource scarcity and the need for innovative approaches to reconstruction, the proposed model can serve as a foundation for crisis response planning and the rationalization of investments in priority sectors. Given the country's current economic challenges, the findings of this research can serve as a strategic framework for reviving and expanding Ukraine's high-tech industries in the long term.

Research Limitations. Despite its comprehensive analysis, this research has certain limitations that must be considered. The econometric model was applied to a specific national economy (Canada), providing valuable insights but necessitating adjustments when applied to other economic contexts to account for variations in market conditions and policy frameworks. Furthermore, the model does not fully incorporate the impact of extraordinary global events, such as pandemics, trade wars, or geopolitical crises, which may lead to significant deviations from projected trends.

Additionally, the research does not differentiate between various high-tech subsectors (e. g., electronics, pharmaceuticals, aerospace), each of which may exhibit distinct cyclical patterns. Future research should refine the model by incorporating sector-specific variables to enhance its predictive capabilities.

Impact of Martial Law Conditions. Although this research was conducted using data from Canada, where economic and industrial conditions remained stable, its application to Ukraine must consider the profound impact of martial law on the country's economy and high-tech sector. The war has introduced unique challenges that significantly affect both the feasibility of implementing high-tech export strategies and the accuracy of economic forecasting models. Unlike Canada, Ukraine's economic stability has been severely disrupted due to industrial destruction, population displacement, and financial instability, leading to limitations in the availability and reliability of economic data. These disruptions alter the traditional patterns observed in high-tech exports, necessitating adjustments in forecasting methodologies to account for external shocks.

Moreover, the role of high-tech exports in Ukraine's economic recovery will differ fundamentally from the cyclical patterns observed in Canada. While economic cycles in stable economies are largely driven by market forces, Ukraine's post-war reconstruction efforts will be influenced by external financial aid, large-scale infrastructure rebuilding, and the urgent need for innovation in defense and critical technologies. This suggests that traditional economic models must be adapted to incorporate the unique drivers of recovery that will shape Ukraine's high-tech sector in the coming years.

Prospects for further research. Future research should expand the dataset to include multiple national economies and adapt the forecasting model to account for wartime economic conditions. Special attention should be given to factors such as industrial losses, shifting export priorities, and the long-term trajectories of postwar economic recovery, which will be essential for developing a tailored strategy for strengthening Ukraine's high-tech sector.

4. Conclusions

The present research has demonstrated the presence of cyclical components in the dynamics of high-tech exports for the period 2007–2020, with cycles of 3.8 and 5.7 years. Cyclical components were also identified in the dynamics of derivative indicators such as the share of high-tech exports in total industrial exports (two harmonics with periods of 3.7 and 3.9 years) and the share in the country's GDP (two harmonics with periods of 14.1 and 3.2 years). This indicates that relative indicators fluctuate in a manner similar to absolute indicators. The overall weighted impact of the cyclical component on the dynamics of high-tech exports is significant, ranging from –14.27% to 13.00%. It should be noted that the negative impact exceeds the positive impact by 1.3%.

The overall weighted impact of the cyclical component on the dynamics of the share of high-tech exports in industrial exports is, on average, 1.2 times lower than the corresponding impact on the dynamics of absolute export values, while in GDP, the influence on the absolute value dynamics is 1.1 times greater.

The identified cycles are associated with the life cycle of technological products, market conditions, and fluctuations in demand in international markets. Therefore, production reserves can be realized by adapting manufacturing capacities to these cycles through: optimizing production planning with consideration of anticipated demand fluctuations; developing flexible manufacturing strategies for rapid adaptation to changes in market conditions; and diversifying the range of high-tech products according to different cycle phases.

The research has revealed periods of accelerated growth, which indicate the presence of technological breakthroughs and increased investment in R&D. However, the subsequent slowdown in exports highlights the underutilization of the country's innovation potential. Potential strategies for identifying reserves include: strengthening collaboration between research centres, universities, and industry to accelerate the implementation of new technologies; applying digital technologies (artificial intelligence, automated production management systems) to enhance productivity; and developing strategies for rapid market entry of new products, reducing the time lag between research and commercial application.

Canada is highly dependent on high-tech exports to the United States. During periods of declining US demand, export volumes tend to decrease. Possible strategies to mitigate this dependency include: increasing the share of exports to European Union and Asian countries; developing new markets, particularly in emerging economies with growing demand for high-tech products; and supporting international cooperative projects to expand the presence of Canadian companies in the global market.

Thus, the analysis of the cyclicality of Canada's high-tech exports allows for the identification of significant production reserves related to flexibility in production strategies, modernization of technological processes, enhancement of financial support, increased efficiency of capacity utilization, and diversification of export markets. Implementing these measures will not only stabilize export dynamics but also ensure sustainable long-term growth of Canada's high-tech sector.

The role of high-tech exports in Ukraine's economic recovery will differ fundamentally from the cyclical patterns observed in Canada. While economic cycles in stable economies are largely driven by market forces, Ukraine's post-war reconstruction efforts will be influenced by external financial aid, large-scale infrastructure rebuilding, and the urgent need for innovation in defense and critical technologies. This suggests that traditional economic models must be adapted to incorporate the unique drivers of recovery that will shape Ukraine's high-tech sector in the coming years.

Future research prospects involve examining similar indicators for Western European countries, North America, East Asia, and Ukraine. Identifying common patterns, systematizing the discovered phenomenon, and developing its classification will be crucial in establishing a scientific basis for the development of a national strategy for the efficient and accelerated economic recovery of Ukraine in the post-war period.

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Conflict of interest

The authors declare that they have no conflicts of interest regarding this research, including financial, personal, authorship, or any other form of conflict that could influence the research and its results presented in this article.

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The manuscript has no associated data.

Use of artificial intelligence

The authors confirm that no artificial intelligence technologies were used in the creation of this work.

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Petro Makarenko, *Doctor of Economic Sciences, Professor, Head of Department of Economics and International Economic Relations, Poltava State Agrarian University, Poltava, Ukraine, ORCID: https://orcid.org/0000-0002-8967-9122*

✉***Oleksandr Belov,*** *PhD, Department of Finance and Accounting, Open International University of Human Development "Ukraine", Kyiv, Ukraine, e-mail: rdnaxel@gmail.com, ORCID: https://orcid.org/0000-0002-7910-8174*

Andrii Makarenko, *Doctor of Economic Sciences, Department of Accounting, Analysis, Taxation and Audit, Zaporizhzhia National University, Zaporizhzhia, Ukraine, ORCID: https://orcid.org/0000-0002-9576-928X*

Lyudmyla Svystun, *PhD, Associate Professor, Department of Finance, Banking and Taxation, National University "Yuri Kondratyuk Poltava Polytechnic", Poltava, Ukraine, ORCID: https://orcid.org/0000-0002-6472-9381*

✉*Corresponding author*