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EDITORS

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Edited by Serhiy Semerikov, Vladimir Soloviev, Andriy Matviychuk, Vitaliy Kobets, Liubov Kibalnyk, Hanna Danylchuk and Arnold Kiv

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FOREWORD

Monitoring, Modeling and Management of Emergent Economy (M3E2) is a peer-reviewed international conference dedicated to scientific achievements in the field of complex systems, the use of information systems and technologies in the economy, interdisciplinary methods, methods of machine learning and fuzzy logic, modeling of socio-economic systems, research global transformations and challenges facing economist scientists. The M3E2 conference is a permanent scientific platform that was launched in 2008 and was formed thanks to the hard work of scientists, practicing researchers, post-graduate students who present the results of their research and have the opportunity to fruitfully discuss them.

M3E2 topics of interest are:

- Complex Cyberphysical Systems, Synergy, Econophysics, Economy of Agents
- Economic Security
- Experimental Economics
- Information Systems and Technologies in Economics
- Innovation Models of Economic Development
- Machine Learning for Prediction of Emergent Economy Dynamics
- Management of the State's Economic Safety and Economic Safety of Economic Agents
- Methods and Models of Artificial Intelligence in Economic Systems
- Modeling of Hospitality Sphere Development
- Models of Global Transformations
- Monitoring, Modeling, Forecasting and Preemption of Crisis in Socio-Economic Systems
- Monitoring, Modeling and Forecasting in the Banking Sector
- Optimal Management of Socio-Economic Processes
- Risk Management Models in Emergent Economy
- The Dynamics of Emergent Markets in Crisis and Post-crisis Period
- The Global Challenges for Economic Theory and Practice in Europe

The proceedings of the 10th International Conference on Monitoring, Modeling, and Management of the Emerging Economy, held November 17-18, 2022, are presented in this book. The book contains 19 papers that were examined by scientists from Ukraine, Poland, Israel, Georgia, the United Kingdom, Romania, Latvia, Portugal, and Pakistan. Each article was examined by at least two program committee members, with an average of 2.8.

We would like to thank all of the researchers of articles who submitted papers and attended the conference. We are also grateful to all of the program committee members who reviewed the submitted materials and provided suitable objective feedback, which helped to improve the articles. Special appreciation to the HotCRP system's developers for allowing all conference attendees to work together in a coordinated and efficient manner.

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Ukrainian Guest Workers in the Labor Market of Poland: Changing Trends in Labor Migration Processes

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Keywords: Guest Workers, Labor Migration, Processes, COVID-19, Economic Factors.

Abstract: The movement of Ukrainian guest workers in the direction of Poland until 2019 was predominantly transnational in nature, as there was a constant movement of labor migrants between the national spaces of Ukraine and Poland with financial participation in the economies of the two countries at the same time. This fact is confirmed by the results of empirical sociological researches conducted by the Ukrainian Institute of the Future, the Cedos analytical agency, the Personnel Service employment agency, the Gremi Personal, and the statistical data of the International Organization for Migration, the State Migration Service of Ukraine, the State Statistics Service of Ukraine, the Ministry of Family and Social Development of Poland. However, the trends changed dramatically due to the global COVID-19 epidemic, later in 2022 with the outbreak of the war in Ukraine. The desire for temporary, pendulum labor mobility gave way to the desire to leave Ukraine forever and settle abroad with the whole family. A new migration trend may be associated with the movement to Poland of Ukrainian men who come after the end of the war to reunite with their families, who were moved there earlier since the beginning of hostilities in Ukraine.

1 INTRODUCTION

The strengthening of the globalization of economic, socio-political processes determines the expediency of studying, both at the theoretical and applied levels, of subjects, causes, consequences, peculiarities of the intensification of labor migration processes, the specificity of which is outlined by socio-spatial and temporal characteristics. Modern transnational labor migration processes have socio-economic differences, contribute to the development of the economic infrastructure of the countries involved in it. At the same time, they create social problems, exerting an ambiguous influence on the labor market, the investment climate, the state of the most important social institutions, and the foreign and domestic political situation. Changes in the content and forms of external labor migration are determined by the nature of the political, administrative and legal, economic and sociocultural determinants that justify and regulate it.

Poland's accession to the EU in 2004 and accession to the Schengen area in 2007 contributed to the elimination of a number of restrictions on the admission of migrant workers. According to the statistics service for the period 2004–2014. amounted to about 2.5 million Polish workers to other EU countries with relatively higher living standards (Ministerstwo Spraw Zagranicznych, 2014). Against the background of successful economic development and record low unemployment, the Polish labor market experienced a shortage of workers, a niche was formed, which was occupied by migrant workers from post-Soviet countries, including Ukraine.

In addition to economic factors, socio-political factors also contributed to the activation of labor migration processes. Thus, 2014 was a turning point for migration, since the military events in the east of Ukraine, the annexation of the Autonomous Republic of Crimea caused a new wave of migration. At the same time, the directions of flows of Ukrainian guest workers to Russia, to the west to the EU, in particular to Poland, have changed significantly. The introduction of a visa-free regime in 2017 significantly simplified and reduced the cost of finding jobs

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and study for Ukrainians abroad, which also helped to strengthen their migration sentiments. The movement of Ukrainian guest workers in the direction of Poland until 2019 was predominantly transnational in nature, as there was a constant movement of labor migrants between the national spaces of Ukraine and Poland with financial participation in the economies of the two countries at the same time. However, the trends have changed dramatically in connection with the global COVID-19 epidemic and severe restrictions on human rights of movement.

2 RELATED WORK

The study of trends in the international movement of Ukrainian labor force in the direction of Poland is relevant from the point of view of coordinating the migration policies of both countries. That is why both Polish (Jaroszewicz (Jaroszewicz, 2014), Iglicka and Gmaj (Iglicka and Gmaj, 2011), etc.) and Ukrainian scientists (Libanova and Pozniak (Libanova and Pozniak, 2020), Kulitskyi (Kulitskyi, 2020), Kulchytska et al. (Kulchytska et al., 2020), Malinovska (Malinovska, 2015)) paid enough attention to the analysis of recent trends in this area. Considering the numerous publications covering the results of various kinds of empirical studies, Polish colleagues studied the problems of labor migration of Ukrainians in much more detail. Whereas most of the Ukrainian developments relate to Poland indirectly, as the problems of external mobility of Ukrainian guest workers were studied only in the context of migration processes in general.

3 RESEARCH QUESTION

The COVID-19 pandemic has made significant changes in the situation of Ukrainian guest workers in Poland, which is why there is an urgent need to investigate the existing changes in labor migration processes trends based on secondary analysis of data of empirical sociological research conducted by the Ukrainian Institute of the Future, the CEDOS analytical agency, the Personnel Service employment agency, the Gremi Personal analytical center of the international employment company, and the statistical data of the International Organization for Migration, the State Migration Service of Ukraine, the State Statistics Service of Ukraine, the Ministry of Family and Social Development of Poland.

4 RESEARCH METHODS

The use of the secondary analysis method made it possible to group the primary sociological information presented in the form of linear distributions and statistical tables in accordance with the objectives of the study. In particular, we are talking about the possibility of comparing the results of empirical sociological research with generalized statistical data published on the official websites of state statistics bodies in order to search for patterns, relationships between variables, generalize data, and study the temporal and spatial dynamics of labor migration processes. To increase the reliability of the analysis of data that were collected by different researchers using various methods of collecting social information, comparison and triangulation methods were used, which made it possible to interpret the existing trends in the labor movements of guest workers.

5 RESULTS

According to the results of 2019, among the countries in the eastern part of Europe, Ukraine closes the four leaders of the origin of emigrants in the region (International Organization for Migration, 2020). Migration flows between Poland and Ukraine have always been exceptionally active. The main prerequisites for such trends are geographical proximity, developed transport links, socio-cultural kinship between these countries. An equally important factor in labor migration is the implementation of legislative initiatives for liberalizing the Polish labor market and providing visa privileges for foreigners.

Since the introduction of the visa regime for crossing the border between Ukraine and Poland in July 2003, the flow of Ukrainians intending to visit the neighboring country has gradually increased from 3.844 million people in 2003 to 9.886 million people in 2019, having acquired its peak in 2017 – 10.410 million people (figure 1).

The data presented capture facts about border crossings and may refer to migrants, tourists, relatives and friends visiting Ukrainian migrants in Poland.

According to the data presented in table 1, in 2017 there were dramatic changes in the distribution of migration flows associated with changes in the issuance – official consolidation of the right to stay for 6-9 months in Poland for foreign workers employed in temporary and seasonal work depending on the sphere of activity.

On the other hand, it should be noted that the nature of employment has changed. In fact, according

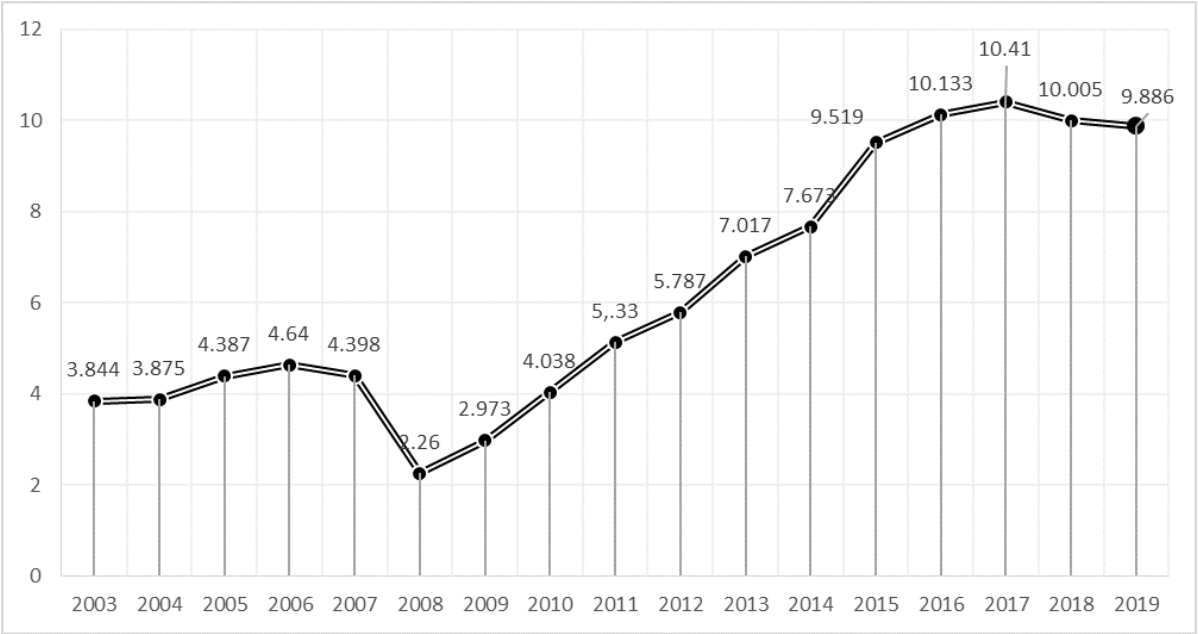

Figure 1: The number of Ukrainians leaving Ukraine for Poland during 2003–2019, million people (based on statistical data (Malinovska, 2015; State Migration Service, 2016, 2017, 2018, 2020, 2019).

Table 1: Distribution of the number of Ukrainians leaving Ukraine for Poland during 2010–2017 by the purpose of their movement (based on statistical data (State Migration Service, 2014, 2016, 2017, 2018).

Year	Purpose of trip			
	Business	Tourism	Private	Service staff
2010	210,6	85,6	3703,4	38,6
2011	207,5	113,6	4781,8	30,4
2012	174,0	69,6	5521,6	21,9
2013	120,2	31,9	6839,6	26,4
2014	98,7	10,9	7547,4	15,7
2015	103,5	10,4	9391,9	13,5
2016	105,1	9,4	9996,6	22,1
2017	1,8	5,1	9984,1	419,3

to the information from the National Bank of Poland, in 2017, compared to 2013, the number of Ukrainians who were seasonally employed in agriculture, forestry, hunting, fishing and other jobs, which do not require a high level of qualification, decreased by more than three times. The number of guest workers employed in industrial production almost doubled, and employment in households, administrative and support services increased by 37,0%.

However, it should be noted that there were relative shifts in such spheres as industrial production, transport, professional, scientific and technical activities, households, administrative and support services (table 2).

Mostly, Ukrainian guest workers in Poland were employed in low-paid jobs, but in 2017 the number of Ukrainians in management positions increased by almost 2,5 times, and the number of legally employed skilled Ukrainian workers increased as well (table 3).

The trends in the structure of the distribution of Ukrainian emigrants by position at the place of their employment, recorded by the data of official statistics, are confirmed by the results of empirical sociological research Polish Labor Market Barometer as well. In fact, in the period 2018-2021, the number of Ukrainian guest workers, who were working at Polish enterprises, holding management positions, continued to grow and increased from 7,4% in 2018 to 12,0% in 2021 (table 4).

Such shifts may be associated with the awareness of the role of Ukrainian migrants in the Polish labor market. Polish employers value Ukrainians for diligence, adaptability, experience (table 5), the majority (72,2%) of them believe that the level of competence of Ukrainians is the same as that of Poles holding similar positions (table 6).

According to the data of the Ministry of Foreign Affairs of Poland in 2019, Polish consulates issued more than 900 thousand visas to Ukrainians, of which 895,7 thousand were national. In 2019, the number of work visas issued to Ukrainians for the first time with a duration of 1 year or more in Poland was up to 44,0 thousand (compared to 28,1 thousand in 2017) (Kulchytska et al., 2020).

The trend of short-term, pendulum or “shuttle” migration of Ukrainian guest workers has given way

Table 2: The structure of legalized employment temporary/ seasonal work of Ukrainian guest workers in the Polish labor market by the type of work permits, % of the total number (Ukrainian Institute of the Future, 2017).

Spheres of employment	Year	
	2013	2017
Agriculture, forestry, hunting and fishing	53,67	17,70
Trade and car service	4,78	3,69
Industrial production	6,94	12,70
Transport	1,84	4,45
Households, administrative and support services	2,49	39,43
Professional, scientific and technical activities	0,55	1,67
Repair, construction and architecture	11,95	12,53
Catering and hotel management	1,47	2,44
Other services and works	16,31	5,41

Table 3: The number of registered Ukrainian employees by the place of work in Poland (Ministerstwo Rodziny i Polityki Społecznej, 2018).

Place of work (profession)	Year							
	2010	2011	2012	2013	2014	2015	2016	2017
Management positions	417	422	489	575	735	1152	2098	5093
Persons who are members of the board of legal organizations	124	126	137	150	142	130	102	675
Skilled workers	3552	6972	7830	5696	9197	22198	43523	79489
Unskilled workers	3397	4318	4665	4801	4744	13108	27337	99071
Information systems engineers, programmers	28	53	43	86	136	702	1245	1500
Artists	96	79	71	70	73	143	191	290
Junior medical staff	20	53	42	50	101	259	311	297
Doctors	10	13	6	5	6	11	119	16
Teachers	68	32	28	28	29	74	151	176

Table 4: Distribution of employers' answers to the question "What positions do Ukrainian citizens occupy in your company?", % of the total number of respondents (Personnel Service, 2017, 2020, 2021).

Positions at enterprises	Year			
	2018	2019	2020	2021
Low-level employees	73,4	71,9	70,0	70,0
Skilled mid-level staff	27,4	20,2	21,0	14,0
Skilled senior staff	7,3	3,9	8,7	12,0
It is difficult to answer	6,4	4,1	0,3	4,0

Table 5: Distribution of employers' answers to the question "What is primarily assessed by your company in employees from Ukraine?", % of the total number of selected answer options (Personnel Service, 2020, 2021).

Virtues of Ukrainian workers	Year	
	2020	2021
Diligence	62,4	42,0
Rapid adaptation	47,4	32,0
Speed of learning	35,6	26,0
Knowledge	30,1	20,0
Creating a positive atmosphere	29,8	15,0
Experience	26,7	32,0
Modesty	24,0	21,0
It is difficult to answer	6,4	4,0

to long-term and sometimes permanent movement. Most manifestations of labor mobility have become legal, but this has not completely excluded the presence of illegal employment. Not only the terms of stay outside Ukraine have changed, but also the directions of movement. If before the events of 2014, mostly residents of the border regions of Ukraine went to neighboring Poland in large numbers, then after 2014 the center of gravity of labor movements shifted slightly to the center of the country. In fact, those Ukrainians who were forced to leave their homes in the Autonomous Republic of Crimea, Luhansk and Donetsk regions, as well as residents of other regions fled outside the national space in search of a better life.

Nor should the assumption of a close two-way relationship between labor and educational migration be rejected. In some places, the existing migration networks of Ukrainian guest workers, pursuing the goals of reuniting parents and children, have caused waves of educational migration. However, such objective factors as the European integration policy of the Ukrainian state, the Bologna process, etc. have also influenced the processes of educational migra-

Table 6: Distribution of employers' answers to the question "How do you assess the competencies of workers from Ukraine compared to Poles working in the same positions?", % of the total number of respondents (Personnel Service, 2019, 2020, 2021).

Level of competence	Year
	2020
More competent	4,7
Just as competent	72,2
Less competent	14,2
It is difficult to answer	8,9

tion.

Thus, the number of Ukrainian students studying in Polish higher education institutions in the 2010–2011 academic year was 3,570 thousand people, while in 2016–2017 – their number increased by 10 times, reaching a total of 355,584 thousand people (Statistics Poland, 2020). According to the study "Ukrainian students in Poland: policies of attraction, integration and motivation and students"plans" conducted by the analytical agency CEDOS during March-May 2018 ($N = 1055$), half of the surveyed Ukrainian educational migrants combine study with work. After completion of their studies in Poland, only 6,0% of Ukrainian students want to return home, 23,0% of respondents intend to stay in this country, 32,0% of students plan to work in the EU countries or outside of it, while all others have not yet decided on their intentions (Stadny, 2019).

Under the conditions of quarantine, the possibilities of e-learning have expanded (Kalashnikova et al., 2022; Vakaliuk et al., 2022). It can be assumed that this is why, in the competition for applicants, which will take place between Ukrainian and Polish higher education institutions, and most likely, the latter will win. Remote forms of organizing the educational process deepen the indicated trend in educational movements, which, in turn, will lead to the emergence of new trends in labor migration processes. Namely, it will contribute not only to a significant rejuvenation of Ukrainian guest workers, but also to intensification of the outflow of highly skilled labor forces.

Many years of migration experience and the existing trends in labor migration processes of recent years have contributed to the formation of migration networks. They, being a form of social capital in the transnational space, significantly increase the likelihood of labor force movements, taking into account the possibility of minimizing the risks associated with finding a job, study, residence, etc. Such networks as an independent factor in intensification of labor mobility, regardless of its root causes (mass unemployment and impoverishment of the population) became the impetus for Ukrainians to move to work to the EU countries in the early 1990s and remain valid to this day. According to the estimates of the State Statistics Service of Ukraine for the period 2015–2017, among Ukrainian labor migrants in Poland, there were 73,0% of those who found a job through friends, relatives, acquaintances, 16,7% – through private individuals, 5,5% – through employers, 5,4% – through private agencies, 8,3% – in other ways (State Statistics Service of Ukraine, 2017).

The data of the Polish Labor Market Barometer (2017–2020) research also confirm the assumptions about the self-continuation of migration through the functioning of labor migration networks, as the most effective way to find Ukrainian workers is family and friend ties. In the second half of 2019, the number of employers' appeals to labor offices in Poland decreased sharply. Instead, searches through social networks and online services in Ukraine intensified. This is confirmed by the fact that in the conditions of quarantine it was extremely difficult for employers to return illegal labor migrants who were forced to return to donor-countries or decided to "sit out" the lockdown in Poland (table 7).

The All-Ukrainian Association of International Employment Companies reported that over the period March-May 2019, about 5-10% of the total number of labor migrants returned to Ukraine. Among them there are mostly those who worked seasonally on short-term contracts. Whereas those who had long-term contracts as well as permanent residence permit in the recipient-countries remained abroad, even having lost their jobs due to the economic crisis caused by the epidemic. Already in May 2020, after the end of the lockdown, most of those who returned to their homeland, went back to work (Libanova and Pozniak, 2020).

The main reason for this was that Polish employers, realizing the dependence of the success of their business on the lack of Ukrainian labor forces, quickly implemented a number of precautionary measures to return and retain workers (providing social guarantees, raising wages, migration amnesty, which provides automatic continuation of the term of work visas for the period of the epidemic and 30 days after its completion, i.e. for two months if the quarantine measures are extended). Thus, in Poland the state program Crisis Shield was being implemented, within the framework of which foreigners who were properly employed, but lost their source of income due to the economic crisis, received social benefits in the amount of about 1400–2080 zlotys (10.3–13.5 thousand hryvnias) (Kulchytska et al., 2020).

According to the data of the Polish Labor Mar-

Table 7: Distribution of employers' answers to the question "How does your company look for or intend to look for employees from Ukraine?", % of the total number of these answer options (Personnel Service, 2019, 2020).

Ways to find Ukrainian workers	Year		
	2017	2019	2020
Through families or friends from Ukraine	35,0	49,0	61,5
Through agencies	48,0	35,8	45,9
Through labor offices in Poland	38,0	7,2	33,4
On online services in Ukraine	23,0	39,3	30,3
Through social media	10,0	19,8	16,0
Through labor offices in Ukraine	15,0	0,5	7,4
It is difficult to answer	0	0	0,4

ket Barometer research during 2017–2021, Polish employers have significantly expanded the areas of social support for Ukrainian labor migrants. Thus, due to quarantine measures in 2020, significantly more companies offered assistance to workers in arranging formalities regarding their official stay in Poland. In 2021, the list of areas of social support included among other things testing for COVID-19, accommodation for quarantine stay after returning to Poland, free insurance in case of COVID-19 illness (table 8).

The analysis of the data shows that if earlier for Ukrainians economic (uneven economic development, desire for material well-being) and social (the possibility of self-affirmation, decent working conditions) motives of international labor force movements prevailed, today it is about a shift towards political (escape from persecution, avoidance of discrimination) and military (conducting military operations on the territory of the native country) motives.

Migrants are more than other groups of the population affected by the introduction of quarantine measures. Competition in the labor market has increased significantly due to mass unemployment caused by the partial suspension of activities or closure of enterprises. According to the assessment of the experts of the Personnel Service employment agency, one in three Polish workers employed in Germany, Austria, Britain and other Western European countries lost his/her job and returned to Poland. Accordingly, the needs of the Polish labor market for cheap labor force of foreign workers, including Ukrainians, have decreased significantly.

This is confirmed by the decrease in the number of vacancies in the Polish labor market, which in 2017 had 152 thousand offers, in 2018 – 165 thousand, in 2020 – 81 thousand. The manufacturing industry suffered the most, where the number of vacancies decreased by 9,8 thousand people, which amounted to 36,0% of the indicators of 2019, construction – by 9,5 thousand (46,0%) and trade – 7.6 thousand (40,0%) (Frączyk, 2020).

Along with socio-economic problems, the problems of xenophobia and intolerance, partially caused by them, became relevant. In particular, we are talking about statements by both the representatives of the indigenous population of the recipient-countries and compatriots who accused labor migrants of spreading coronavirus infection.

According to the results of the Polish Labor Market Barometer research during 2017-2021 the nature of the attitude of employers towards emigrants from Ukraine has changed significantly. Thus, in 2021, compared to 2017, the number of those who have a negative attitude towards Ukrainian guest workers has increased by 8 times. On the other hand, the number of Poles who evaluate them positively has doubled (table 9). Such shifts took place mainly due to the delineation of their personal attitude of those employers who in 2017 characterized their attitude as neutral.

In order to verify the hypotheses about the existing shifts in the trends of international labor movements of Ukrainians in the context of a pandemic, an attempt was made to systematize the results of an empirical sociological study conducted by the analytical center of international employment company Gremi Personal (Poland) in February 2020 with the usage of technologies of computerized telephone survey system CASI among 1,100 thousand Ukrainian guest workers who worked in Poland (Our Poland, 2021).

The first shifts in the trends of transnational labor migration are associated with the rejuvenation of the contingent of guest workers, as the majority of the working population is leaving – under the age of 39. Ukraine continues to lose its intellectual elite, since a third of migrant respondents have higher education (28,4%) and every second informant has a vocational or specialized secondary education (47,8%).

The vast majority of respondents (68,3%) are to some extent satisfied with the working conditions in Poland. Among the main reasons for leaving their own homeland, respondents focused on significantly higher wages compared to Ukraine (80,6%), the stable economic situation in Poland (27,9%) and the op-

Table 8: Distribution of employers' answers to the question "What additional types of assistance do you offer to your employees from Ukraine?", % of the total number of these answer options (Personnel Service, 2019, 2020, 2021).

Types of assistance	Year			
	2017	2019	2020	2021
Assistance in arranging formalities	37,0	49,3	67,2	35,0
Social payments	25,0	39,1	49,3	24,0
Accommodation	24,0	30,1	40,7	27,0
Transport to the workplace	19,0	18,4	25,4	22,0
Internet	12,0	10,9	16,5	15,0
Food	9,0	14,0	15,1	15,0
Accommodation for quarantine time	-	-	-	20,0
Testing for COVID-19	-	-	-	16,0
Free health insurance against COVID-19	-	-	-	12,0
Food	9,0	14,0	15,1	15,0
We do not offer anything	24,0	15,0	10,0	8,0
It is difficult to answer	0	0	0,6	0

Table 9: Distribution of employers' answers to the question "What is the attitude of your company as an employer to employees from Ukraine?", % of the total number of respondents (Personnel Service, 2019, 2020, 2021).

Attitude	Year			
	2017	2019	2020	2021
Mostly positive	7,0	8,6	8,8	14,0
Positive	22,0	34,1	24,0	22,0
Neutral	71,0	46,8	56,0	49,0
Negative	0	0,3	1,7	5,0
Mostly negative	0	0,8	0,7	3,0
It is difficult to answer	0	9,4	8,8	7,0

portunity to get a work visa or temporary residence permit, which is relatively easier than in other EU countries (25,4%). Guest workers consider the lack of jobs in Ukraine (70,9%), the poor economic situation (49,0%), the lack of prospects, opportunities for self-realization (23,2%), political instability (22,8%), and corruption (14,0%) to be the inhibitory factors for returning home. At the same time, curiously enough, the least of all informants are worried about the military conflict in the east of the country (7,2%), loss of business (4,1%), crime (1,2%) or poor quality medical care (3,1%).

One in five respondents (18,6%) is dissatisfied with the attitude of Poles towards them at work, especially noting the growing trends of discrimination in the context of a pandemic.

Speaking about integration intentions, it should be noted that half of the respondents (46,4%) expressed a desire to stay and live in Poland. More than a third of respondents (35,1%) do not consider the possibility of returning to Ukraine at all. A direct confirmation of these trends is the intention of the majority of guest workers (66,5% in 2021, compared to 60,0% in 2020) to obtain a permanent residence permit in Poland. In addition, 51,7% (compared to 41,0% in 2020) of Ukrainians plan to move their families to Poland. Also significant is the desire of Ukrainian migrant workers to open their own business in Poland – in 2020, 25,0% respondents had such intentions, while in 2021 there were significantly more applicants (39,8%). The number of migrants considering the possibility of buying their own housing and other real estate in Poland has doubled, from 34,0% in 2020 to 55,5% in 2021.

A noticeable increase in all these indicators testifies an increase in the integration sentiments of Ukrainians, a significant expansion of transnational spaces. More than half of the informants (54,1%) expressed their intention to continue moving to other EU countries in search of work in the event of a worsening situation in Poland due to the pandemic. This trend, even taking into account the pandemic and lockdown, has not changed compared to the results of similar studies conducted in 2020. Among the most acceptable areas of possible labor mobility, Ukrainians consider Germany, Scandinavian countries, the Czech Republic, Canada and the United States. In particular, interest in the Scandinavian countries has almost doubled (42,5% of respondents in 2021 compared to 22,0% in 2020).

In the study "Foreign worker in the era of a pandemic", conducted by EWL SA, the Foundation for the Support of Migrants in the Labor Market "EWL" and the Center for Eastern European Studies at the University of Warsaw in the period April-May 2021 took part labor migrants who were in Poland during the pandemic ($N = 620$ people, including 92,4% from Ukraine, 4,2% from Belarus, 2,3% from Moldova and 1,1% from other countries) (table 10).

Table 10: Distribution of employers' answers to the question "What arguments prompted you to stay in Poland during the epidemic?" (respondents who were working in Poland at the time of the outbreak of the pandemic) (Zymnin et al., 2021).

Answer options	Year
	2021
I worked in Poland before the outbreak of the pandemic and did not want to change my plans	50,0
I would like to continue employment in Poland as long as there is such a possibility	36,7
My permits for legal residence and work have been automatically extended	24,3
There is a job shortage in my country during a pandemic	23,0
During the pandemic I feel safer in Poland than in my country	12,8
No I will be able to come to Poland for a longer time	7,1
The health service in Poland functions better than in my country	6,2
The health service in Poland functions better than in my country	6,2
After returning to my home country I will be forced / forced to go to quarantine	4,9
My employer convinced me to stay	4,9
Other	4,4

The data obtained indicate that 27,0% of respondents declare that due to the pandemic they had to find a new job in Poland. 79,0% migrants will recommend work in Poland to their friends and relatives. 91,0% foreigners do not regret that remained in Poland during the pandemic. 55,0% respondents have used or are planning to take advantage of the automatic renewal of permits to stay and work in Poland. For 36,0% of foreigners, the biggest difficulty during work in Poland during a pandemic is separation from their families. This is most likely related to this. the reason, and also due to the introduction of rules aimed at avoiding the quarantine, more and more foreigners decide to travel despite the ongoing epidemic. In September 2020, every fifth respondent left Poland during the pandemic. In May 2021, this figure was already 37,0% of the respondents. 51,0% of foreigners are interested in working in Germany, Poland ranks in second place – 48,0% of respondents want to work with us. Are also rated high in the ranking Czech Republic (26,0%), USA (25,0%), Canada (23,0%) and Norway (21,0%) (Zymnin et al., 2021).

6 CONCLUSION

The change in the trends of transnational labor migration of Ukrainians by the beginning of 2019 provided a shift in the center of gravity towards the EU, in particular Poland, strengthening the relationship between such types of movement as educational and labor migration, and a significant rejuvenation of guest workers. The desire for temporary, pendulum labor mobility gave way to the desire to leave Ukraine forever and settle abroad with the whole family. After 2019, in the context of the COVID-19 pandemic, the situation only worsened, because no more than 5-10% of the total number of guest workers returned home. This, in its turn, indicates a qualitative change in the motivation of labor movements, even despite the temporary increase in xenophobia and intolerance.

Quarantine measures are unlikely to significantly change the intentions of Ukrainians to leave Ukraine for Poland. In fact, despite the existing panic among Ukrainian guest workers, which was provoked by the first lockdown in the spring of 2019, the number of those who returned home did not exceed 5-10%. And after the relative stabilization of the situation in the EU, in particular in Poland, the majority of migrant workers went abroad to work again. This is evidenced by the steady increase in the number of Ukrainian guest workers in Poland in the second half of 2020.

In contrast to the state bodies of Poland, the Ukrainian authorities are showing outright inactivity towards the regulation of labor migration processes. Ukraine still does not even have an effective mechanism for recording international illegal labor movements, not to mention projects to regulate labor flows at the level of state migration policy. Despite significant losses of human capital and deepening demographic crisis, the Ukrainian government has relied on increasing revenues to the country's budget, considering labor movements as a direction of investment in the Ukrainian economy and a way to reduce unemployment, maintenance and social security of low-income citizens. This is eloquently evidenced by statistics – according to the data of the National Bank of Ukraine, the volume of private remittances in 2020 reached a record 12.1 billion dollars, which is about 10,0% of Gross Domestic Product of the country (National Bank of Ukraine, 2021). Until the Ukrainian economy generates enough jobs, provides decent working conditions and high wages, taking into account the available human capital, Ukrainian

employers will increasingly suffer from a lack of skilled workers, losing the struggle for labor resources in the global labor market, and Ukraine will remain the main supplier of highly skilled workers for the EU countries, including Poland.

The war in Ukraine actualizes a new round of labor migration processes. New trends will be associated, firstly, with the return of male labor migrants from the EU countries, the USA, Canada and other countries to Ukraine, and secondly, with the activation of both internal and external forced displacements of the labor force.

Active hostilities in Ukraine in 2022 caused a new wave of migration to Poland, which is characterized by the movement of mainly women with children for an indefinite period of time. As a result of the movement of such a specific socio-demographic group, the demand for educational, medical and social services has increased, and the number of workers employed in these areas has increased. A new migration trend may be associated with the movement to Poland of Ukrainian men who come after the end of the war to reunite with their families, who were moved there earlier since the beginning of hostilities in Ukraine. The new tendencies of labor migration, caused by the war, require their detailed study, in particular with the help of sociological tools.

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Fuzzy Expert System of the Decision Making Support on Foreign Direct Investment

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Keywords: Fuzzy Expert Decision Support System, Foreign Direct Investment, Swarm Metaheuristics, Optimization Methods, Operator.

Abstract: The fuzzy expert decision support system for foreign direct investment was developed in the research. A quality criterion was chosen for the proposed fuzzy expert system, which considers the created fuzzy expert system's specifics and allows assessing the probability of future decisions. A metaheuristic method was created based on an adaptive gravitational search algorithm to determine the parameters of the proposed fuzzy expert system. A numerical study was carried out; the parameters of membership functions for linguistic input variables were determined; the parameters of the membership functions for the values of the linguistic output variable were determined. The proposed optimization method based on swarm metaheuristics and a fuzzy expert system make it possible to intellectualize the technology of making decisions on foreign direct investment.

1 INTRODUCTION

The decision-making systems for foreign direct investment are very popular nowadays. The regression (Milovanović and Marković, 2022) and autoregressive (Kurecic and Kokotovic, 2017) methods are usually used to create decision-making systems for foreign direct investment based on machine learning. The construction of only linear models is the disadvantage of such methods. The knowledge base (most often in the form of production rules) and an inference mechanism are used to create decision-making systems for foreign direct investment based on expert systems (Šamanović et al., 2010). The disadvantages of such systems include the fact that they operate only with quantitative estimates, while it is easier for the operator to work with qualitative estimates.

The fuzzy expert systems are currently used to simplify the interaction between a human and a computer system. These expert systems usually use the Larsen, Mamdani, Tsukamoto, and Sugeno fuzzy inference mechanisms (Ruan, 1997; Tsoukalas and Uhrig, 1997).

The disadvantages of such systems include the fact that the procedure for determining their parameters is not automated (Abe, 1997; Rotshtein et al., 2001). The optimization methods are currently actively used to determine the parameters of fuzzy expert systems.

Modern optimization methods suffer from one or more of the following disadvantages:

- have high computational complexity;
- fall into a local extremum with a high probability;
- do not guarantee convergence.

In this regard, there is an actual problem of optimization methods' insufficient efficiency.

Metaheuristics (modern heuristics) are used to speed up finding a quasi-optimal solution to optimization problems and reduce the probability of hitting a local extremum (Talbi, 2009; Engelbrecht, 2007; Yu and Gen, 2010; Nakib and Talbi, 2017; Yang, 2018a; Subbotin et al., 2016). Metaheuristics expand the possibilities of heuristics by combining heuristic methods based on a high-level strategy (Blum and Raidl, 2016;

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Glover and Kochenberger, 2003; Yang, 2018b; Martí et al., 2018; Gendreau and Potvin, 2019).

Modern metaheuristics suffer from one or more of the following disadvantages:

- insufficient method accuracy (Alba et al., 2013);
- there is only an abstract description of the method or the description of the method is focused on solving only a specific problem (Doerner et al., 2007);
- the procedure for determining parameter values is not automated (Grygor et al., 2019);
- the influence of the iteration number on the solution search process is not taken into account (Bozorg-Haddad, 2017);
- there is no possibility to solve problems of conditional optimization (Fedorov et al., 2019);
- there is no possibility to use non-binary potential solutions (Radosavljević, 2018);
- the method convergence is not guaranteed (Chopard and Tomassini, 2018).

In this regard, the problem of constructing efficient metaheuristic optimization methods arises (Du and Swamy, 2016; Brownlee, 2011).

One of the popular metaheuristics is the gravitational search algorithm (Rashedi et al., 2009), which belongs to swarm metaheuristics.

The task of building fuzzy expert systems that use the method of parametric identification for adaptation and tuning is actual for our research.

The *goal* of this research is to improve the efficiency of decisions on foreign direct investment by creating a fuzzy expert system trained based on metaheuristics.

The following tasks were set and solved:

1) to develop a fuzzy expert decision support system for foreign direct investment;
2) to select a quality criterion for the proposed fuzzy expert system;
3) to create a metaheuristic method based on an adaptive gravitational search algorithm to determine the proposed fuzzy expert system parameters;
4) to conduct numerical research.

2 THE FUZZY EXPERT DECISION SUPPORT SYSTEM FOR FOREIGN DIRECT INVESTMENT

The foreign direct investment analysis is based on the data of the GDP per capita volume, inflation rates, goods and services exports volume, and labor force indicators. To make decisions on foreign direct investment, a fuzzy expert system is proposed. It involves the following steps:

1) linguistic variables formation;
2) fuzzy knowledge base formation;
3) Mamdani fuzzy inference mechanism formation:
   - fuzzification;
   - sub-conditions aggregation;
   - conclusions activation;
   - aggregation of conclusions;
   - defuzzification.
4) identification of parameters based on metaheuristics.

2.1 Linguistic Variables Formation

The following input variables were chosen:

- the volume of gross domestic product (GDP) per capita (per year, US dollars), x_1;
- the inflation indicator (according to the consumer price index, which reflects the annual percentage change in the cost for the average consumer of purchasing a goods and services basket, per year, %), x_2;
- the volume of goods and services export indicator (total volume, per year, USD), x_3;
- the labor force indicator (labor force is people aged 15 and over who provide labor for the production of goods and services, per year, number of people), x_4.

The following indicators were chosen as linguistic input variables. They are qualitative indicators:

- the GDP volume $\tilde{x}_1$ with values $\widetilde{\alpha}_{11} = \mathit{little}$, $\widetilde{\alpha}_{12} = \mathit{medium}$, $\widetilde{\alpha}_{13} = \mathit{much}$, where the ranges are fuzzy sets $\tilde{A}_{11} = \{(x_1, \mu_{\tilde{A}_{11}}(x_1))\}$, $\tilde{A}_{12} = \{(x_1, \mu_{\tilde{A}_{12}}(x_1))\}$, $\tilde{A}_{13} = \{(x_1, \mu_{\tilde{A}_{13}}(x_1))\}$;
- the inflation indicator $\tilde{x}_2$ with values $\widetilde{\alpha}_{21} = \mathit{little}$, $\widetilde{\alpha}_{22} = \mathit{medium}, \widetilde{\alpha}_{23} = \mathit{much}$, where the ranges are fuzzy sets $\tilde{A}_{21} = \{(x_2, \mu_{\tilde{A}_{21}}(x_2))\}$, $\tilde{A}_{22} = \{(x_2, \mu_{\tilde{A}_{22}}(x_2))\}$, $\tilde{A}_{23} = \{(x_2, \mu_{\tilde{A}_{23}}(x_2))\}$;

- the volume of goods and services export indicator $\tilde{x}_3$ with values $\widetilde{\alpha}_{31} = little$, $\widetilde{\alpha}_{32} = medium$, $\widetilde{\alpha}_{33} = much$, where the ranges are fuzzy sets $\tilde{A}_{31} = \{(x_3, \mu_{\tilde{A}_{31}}(x_3))\}$, $\tilde{A}_{32} = \{(x_3, \mu_{\tilde{A}_{32}}(x_3))\}$, $\tilde{A}_{33} = \{(x_3, \mu_{\tilde{A}_{33}}(x_3))\}$;
- the labor force indicator $\tilde{x}_4$ with values $\widetilde{\alpha}_{41} = little$, $\widetilde{\alpha}_{42} = medium$, $\widetilde{\alpha}_{43} = much$, where the ranges are fuzzy sets $\tilde{A}_{41} = \{(x_4, \mu_{\tilde{A}_{41}}(x_4))\}$, $\tilde{A}_{42} = \{(x_4, \mu_{\tilde{A}_{42}}(x_4))\}$, $\tilde{A}_{43} = \{(x_4, \mu_{\tilde{A}_{43}}(x_4))\}$.

The volume of foreign direct investment (net flows for the year, USD) was chosen as a clear output variable $\tilde{y}$. It is a qualitative indicator.

The volume of foreign direct investment was chosen $\tilde{y}$ with its values $\widetilde{\beta}_1 = little$, $\widetilde{\beta}_2 = medium$, $\widetilde{\beta}_3 = much$, where the ranges are fuzzy sets $\tilde{B}_1 = \{(y, \mu_{\tilde{B}_1}(y))\}$, $\tilde{B}_2 = \{(y, \mu_{\tilde{B}_{42}}(y))\}$, $\tilde{B}_3 = \{(y, \mu_{\tilde{B}_3}(y))\}$;

2.2 Fuzzy Knowledge Base Formation

Fuzzy knowledge is represented as the following fuzzy rules that contain a linguistic output variable R^n : IF $\tilde{x}_1$ is $\tilde{a}_{1i}$ AND $\tilde{x}_2$ is $\tilde{a}_{2j}$ AND $\tilde{x}_3$ is $\tilde{a}_{3k}$ AND $\tilde{x}_4$ is $\tilde{a}_{4p}$ then $\tilde{y}$ is $\tilde{B}_m$

In the case of linguistic variables specific values, fuzzy knowledge is presented in relational form in table 1.

Table 1: Relational form of fuzzy knowledge representation.

The rule	$\tilde{x}_1$	$\tilde{x}_2$	$\tilde{x}_3$	$\tilde{x}_4$	$\tilde{y}$
R^1	$\widetilde{\alpha}_{11}$	$\widetilde{\alpha}_{21}$	$\widetilde{\alpha}_{31}$	$\widetilde{\alpha}_{41}$	$\widetilde{\alpha}_1$
R^2	$\widetilde{\alpha}_{12}$	$\widetilde{\alpha}_{21}$	$\widetilde{\alpha}_{31}$	$\widetilde{\alpha}_{41}$	$\widetilde{\alpha}_1$
R^3	$\widetilde{\alpha}_{13}$	$\widetilde{\alpha}_{21}$	$\widetilde{\alpha}_{31}$	$\widetilde{\alpha}_{41}$	$\widetilde{\alpha}_2$
R^4	$\widetilde{\alpha}_{11}$	$\widetilde{\alpha}_{22}$	$\widetilde{\alpha}_{31}$	$\widetilde{\alpha}_{41}$	$\widetilde{\alpha}_2$
...	...	...	...	...	...
R^{81}	$\widetilde{\alpha}_{13}$	$\widetilde{\alpha}_{23}$	$\widetilde{\alpha}_{33}$	$\widetilde{\alpha}_{43}$	$\widetilde{\alpha}_3$

2.3 Mamdani Fuzzy Inference Mechanism Formation

2.3.1 Fuzzification

We will determine the truth degree of each sub-condition of each rule, using the membership function $\mu_{\tilde{A}_{ij}}(x_i)$.

As membership functions of sub-conditions, we chose:

- piecewise linear Z-shaped function, i.e.

$$\mu_{\tilde{A}_{i1}}(x_i) = \begin{cases} 1, & x_i \le a_i \\ \frac{b_i - x_i}{b_i - a_i}, & a_i < x_i < b_i \\ 0, & x_i \ge b_i \end{cases}, i \in \overline{1,4}$$

- piecewise linear Π-shaped function, i.e.

$$\mu_{\tilde{A}_{i2}}(x_i) = \begin{cases} 0, & x_i \le a_i \\ \frac{x_i - a_i}{b_i - a_i}, & a_i \le x_i \le b_i \\ 1, & b_i \le x_i \le c_i \\ \frac{d_i - x_i}{d_i - c_i}, & c_i \le x_i \le d_i \\ 0, & x_i \ge d_i \end{cases}, i \in \overline{1,4}$$

- piecewise linear S-shaped function, i.e.

$$\mu_{\tilde{A}_{i3}}(x_i) = \begin{cases} 0, & x_i \le c_i \\ \frac{x_i - c_i}{d_i - c_i}, & c_i < x_i < d_i \\ 1, & x_i \ge d_i \end{cases}, i \in \overline{1,4},$$

where a_i, b_i, c_i, d_i - membership function parameters.

2.3.2 Sub-Condition Aggregation

The condition membership functions for each rule R^n are determined based on the minimum value method:

$$\mu_{\bigcup_{i=1}^{4} \tilde{A}_{i,f(n,i)}}(x_1, x_2, x_3, x_4) = \min_{i \in \overline{1,4}} \left\{ \mu_{\tilde{A}_{i,f(n,i)}}(x_i) \right\},$$

where f – a function that returns the value number of the i-th linguistic input variable of the n-th rule and is determined on the basis of table 1. For example, if the linguistic input variable $\tilde{x}_1$ rules R^{81} matters $\widetilde{\alpha}_{13}$, then $f(81,1) = 3$.

2.3.3 Activation of Conclusions

The membership functions of the conclusion for each rule R^n are determined based on the minimum value method (based on the Mamdani rule):

$$\mu_{\tilde{B}_{g(n)}}(y) = \min \left\{ \mu_{U_{i=1}^{4} \tilde{A}_{i,f(n,i)}}(x_1, x_2, x_3, x_4), \mu_{\tilde{B}_{g(n)}}(y) \right\},$$

where g – a function that returns the value number of the linguistic output variable of n-th rule and determined on the basis of table 1.

For example, if the linguistic output variable $\tilde{y}$ of the rule R^{81} is $\widetilde{\beta}_3$, then $g(81) = 3$.

A piecewise linear triangular function was chosen as the membership functions of the conclusions, i.e.

$$\mu_{\tilde{B}_m}(y) = \begin{cases} 0, & y \le e_m \\ \frac{y - e_m}{u_m - e_m}, & e_m \le y \le u_m \\ \frac{v_m - y}{v_m - u_m}, & u_m \le y \le v_m \\ 0, & y \ge v_m \end{cases}, m \in \overline{1,3},$$

where e_m, u_m, v_m – membership function parameters.

In the case of such a membership function, the kernel of each fuzzy set $\tilde{B}_m$ is:

$$\ker \tilde{B}_m = \{ y \in Y | \mu_{\tilde{B}_m}(y) = 1 \} = \{ u_m \}.$$

2.3.4 Aggregation of Conclusions

The membership functions of the final conclusion are defined, which contains a linguistic output variable based on the maximum value method:

$$\mu_{\tilde{B}_m}(Y) = \max_{n\in 1,81}\{\mu_{\tilde{B}_g(n)}(y)\}$$

2.3.5 Defuzzification

The volumes of foreign direct investment are determined basedon the centroid method:

$$y^* = \frac{\sum_{y\in Y}\mu_{\tilde{B}}(y)y}{\sum_{y\in Y}\mu_{\tilde{B}}(y)}, Y = \{1,2,3\}$$

3 QUALITY CRITERION FOR THE PROPOSED FUZZY EXPERT SYSTEM

The objective function is chosen as a quality criterion, representing the accuracy as probability of correct foreign direct investment

$$F = \frac{1}{P}\sum_{p=1}^{P},[y_p = d_p] \to \max_{\theta}, \quad [p=q] = \begin{cases} 1, & p=q \\ 0, & p\neq q \end{cases}, \tag{1}$$

where d_p – test foreign direct investment,

y_p – foreign direct investment received as a result of fuzzy inference,

P – number of test implementations,

$\theta = (a_1,b_1,c_1,d_1,...,a_4,b_4,c_4,d_4,e_1,u_1,v_1,...,e_3, u_3,v_3)$ – parameter vector of membership functions.

4 METAHEURISTIC METHOD BASED ON AN ADAPTIVE GRAVITATIONAL SEARCH ALGORITHM FOR DETERMINING THE PARAMETERS OF THE PROPOSED FUZZY EXPERT SYSTEM

The particle velocity (not the gravitational constant) depends on the iteration number in this method, which provides control over the convergence rate of the method, as well as providing a global search at the initial iterations, and a local search at the final iterations. The parameter vector of membership functions corresponds to the position vector of one particle x. The quality criterion is used as the goal function (1).

1. Initialization.

1.1. Setting the gravitational constant G, the maximum number of iterations N, the population size K, the length of the particle position vector M (it corresponds to the length of the parameter vector of membership functions and is equal to 25), the minimum and maximum values for the position vector $x_j^{\min}$, $x_j^{\max}$, $j \in \overline{1,M}$, the minimum and maximum values for the velocity vector $v_j^{\min}$, $v_j^{\max}$, $j \in \overline{1,M}$.

1.2. The best position vector randomly generating $x^* = (x_1^*,...,x_M^*)$,
$x_j^* = x_j^{\min} + (x_j^{\max} - x_j^{\min})U(0,1)$,
where $U(0,1)$ – a function that returns a uniformly distributed random number in a range $[0,1]$.

1.3. The initial population creation

1.3.1. Particle number $k = 1$, $P = \emptyset$.

1.3.2. A position vector at random x_k generating $x_k = (x_{k1},...,x_{kM})$,
$x_{kj} = x_j^{\min} + (x_j^{\max} - x_j^{\min})U(0,1)$.

1.3.3. Random velocity vector v_k generating $v_k = (v_{k1},...,v_{kM})$,
$v_{ij} = v_j^{\min} + (v_j^{\max} - v_j^{\min})U(0,1)$.

1.3.4. If $(x_k,v_k) \notin P$, then $P = P \cup \{(x_k,v_k)\}$, $k = k+1$.

1.3.5. If $k \leq K$, then go to step 1.3.2.

2. Iteration number $n = 1$.

3. The computation of the best and worst particle of a population from a target function

$$l = arg\min_k F(x_k), x^{best} = x_l,$$
$$l = arg\max_k F(x_k), x^{worst} = x_l.$$

4. The computation of all particles masses.

5. The computation of the gravitational force acting between all pairs of particles

5.1. $m_k = G\frac{F(x_k)-F(x^{worst})}{F(x^{best})-F(x^{worst})}, k \in \overline{1,K}$.

5.2. $M_k = \frac{m_k}{\sum_{s=1}^{K} m_s}, k \in \overline{1,K}$.

6. The computation of the gravitational force acting between all pairs of particles

$$f_{kl} = G\frac{M_k M_l}{d(x_k,x_l)+\varepsilon}(x_l - x_k), k,l \in \overline{1,K},$$

where $d(x_k,x_l)$ – distance between particles k and l (e.g. Euclid distance).

7. The computation of the resulting force acting on all particles

$$r_{kl} = U(0,1), k,l \in \overline{1,K}$$

$$f_k = \sum_{\substack{l=1 \\ l \neq k}}^{K} r_{kl} f_{kl}, k \in \overline{1,K}$$

8. Modification of the acceleration of all particles

$$a_k = \frac{f_k}{M_k}, k \in \overline{1,K}$$

9. Speed modification of all particles

$$r_k = U(0,1), k \in \overline{1,K}$$

$$v_k = r_k v_k + a_k, k \in \overline{1,K}$$

10. Modification all of the particles' position, taking into account the iteration number
    10.1. $x_k = x_k + v_k \left(1 - \frac{n}{N}\right), k \in \overline{1,K}$
    10.2. $x_{kj} = \max\{x_j^{\min}, x_{kj}\}, x_{kj} = \min\{x_j^{\max}, x_{kj}\}, j \in \overline{1,M}, k \in \overline{1,K}$
11. If $n < N$, then $n = n+1$, go to step 3
    The result is x^*.

5 NUMERICAL RESEARCH

Numerical research was carried out using the Keras submodule of the TensorFlow module. The Pandas module was used to fill in missing values through linear interpolation, as well as for tabular data I/O operations. The Scikit-fuzzy module was used to create a fuzzy expert system.

The fuzzy expert system was researched using the World Bank economic indicators database (https://databank.worldbank.org/home.aspx). The economic indicators of 145 countries for 10 years were used. The size of the original sample was 1450.

For the proposed adaptive gravity search algorithm, the gravity constant G was 100, the maximum number of iterations was 1000, and the population size was 50.

The comparison results of the proposed fuzzy expert system with the operator are presented in table 2.

Table 2: Comparison results of the proposed fuzzy expert system with an operator.

Accuracy	
fuzzy expert system	operator
0.98	0.8

The comparison results of the proposed fuzzy expert system with the proposed meta-heuristic adaptive gravitational search algorithm (AGSA) and the traditional meta-heuristic adaptive gravitational search algorithm (AGSA) operator are presented in table 3.

Table 3: Comparison results of the proposed fuzzy expert system of the proposed meta-heuristic and the traditional meta-heuristic.

Accuracy	
GSA	AGSA
0.93	0.98

Figure 1 shows the accuracy for the proposed fuzzy expert system trained based on the proposed meta-heuristic adaptive gravitational search algorithm (AGSA) and on the proposed meta-heuristic gravitational search algorithm (GSA).

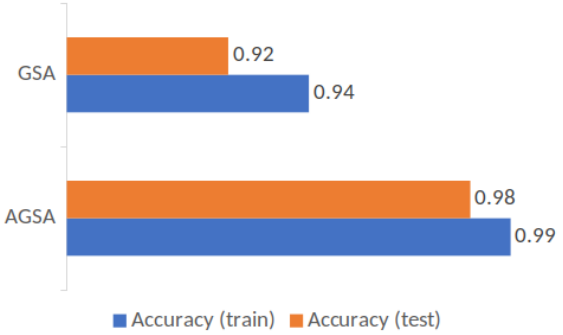

Figure 1: Accuracy of the proposed fuzzy expert system with GSA and AGSA.

The comparison results of the proposed fuzzy expert system trained on the basis of back-propagation (BP) and the proposed meta-heuristic adaptive gravitational search algorithm (AGSA) are presented in table 4.

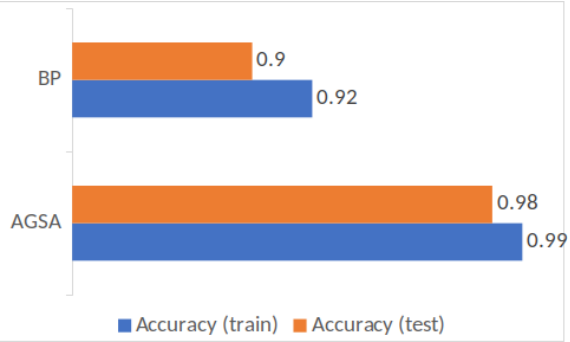

Figure 2: Accuracy of the proposed fuzzy expert system with BP and AGSA.

Figure 2 shows the accuracy for the proposed

Table 4: Comparison results of the proposed fuzzy expert system based on the back-propagation method and proposed meta-heuristic.

Accuracy	
BP	AGSA
0.90	0.98

fuzzy expert system trained on the basis of back-propagation (BP) and the proposed meta-heuristic adaptive gravitational search algorithm (AGSA).

Figures 3-7 shows the membership functions for the values of linguistic variables $\tilde{x}_1$, $\tilde{x}_2$, $\tilde{x}_3$, $\tilde{x}_4$ and y.

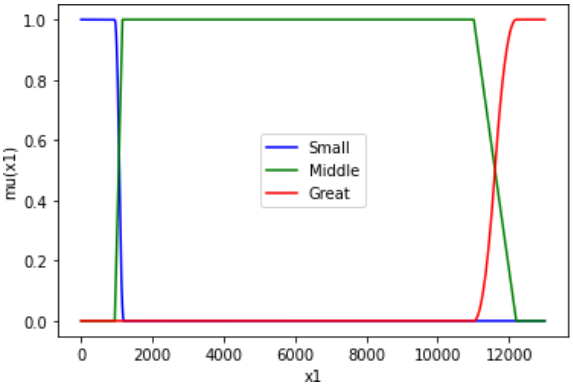

Figure 3: Membership functions for linguistic variable values $\tilde{x}_1$.

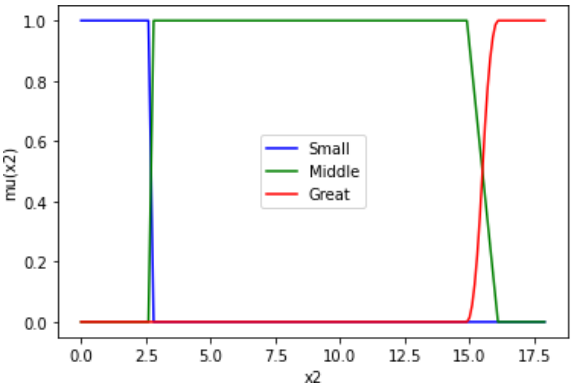

Figure 4: Membership functions for linguistic variable values $\tilde{x}_2$.

6 DISCUSSION

The traditional non-automatic approach to assessing the foreign direct investment effectiveness reduces the accuracy of a correct assessment (table 2). The proposed method eliminates this disadvantage.

The traditional method of the gravitational search algorithm ignores the iteration number during the particle position calculating; this reduces the accuracy of finding a solution (table 3); requires a large number of parameters associated with the gravitational constant calculating. The proposed method eliminates these shortcomings.

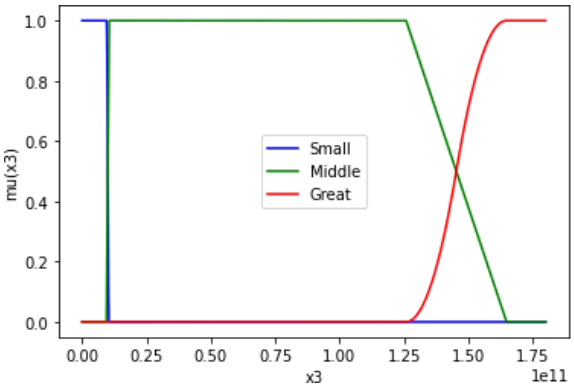

Figure 5: Membership functions for linguistic variable values $\tilde{x}_3$.

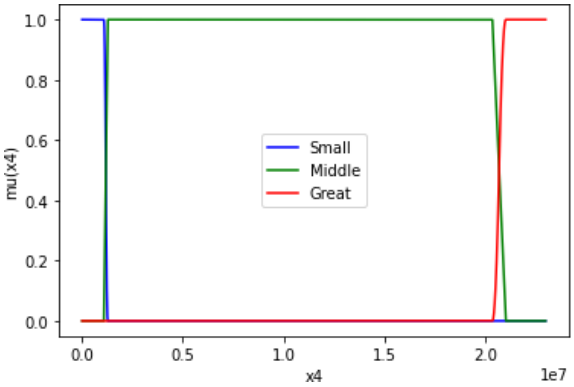

Figure 6: Membership functions for linguistic variable values $\tilde{x}_4$.

The traditional approach to training a fuzzy expert system based on back propagation reduces the probability of correct estimation (table 4). The proposed method eliminates this disadvantage.

7 CONCLUSIONS

1. Relevant optimization methods and expert systems were investigated as part of the decision-making technology for foreign direct investment. The research results showed that the most effective is the use of fuzzy expert systems, the parameters of which are identified by means of meta-heuristic methods today.
2. A fuzzy expert decision support system for foreign direct investment has been developed. The proposed system simplifies the interaction between the operator and the computer system

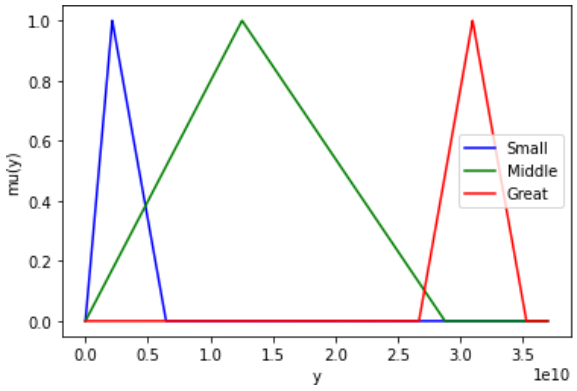

Figure 7: Membership functions for linguistic variable values $\tilde{y}$.

through the use of qualitative indicators, and also allows to identify its parameters using the proposed swarm metaheuristics.

3. A quality criterion is proposed; it considers the specifics of the created fuzzy expert system and allows assessing of the decisions accuracy.

4. A swarm metaheuristic algorithm based on an adaptive gravitational search algorithm has been created; it provides control over the rate of method convergence, as well as providing global search at the initial iterations, and local search at the final iterations due to adaptive control of the particle velocity.

5. The proposed optimization method based on swarm metaheuristics and a fuzzy expert system make it possible to intellectualize the technology of making decisions on foreign direct investment. Prospects for further research involve testing the proposed method and system on a wider test database set.

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Multidimensional Analysis of Educational Indicators of the National Economy Innovative Development

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Keywords: Educational Indicators, Educational Performance, Innovative Development, Educational and Scientific Breakthrough, National Economy.

Abstract: The paper is a study of the educational indicators signifying the national economy innovative development. The subject of the research is the processes defining the formation and advancement of prerquisites for educational and scientific breakthrough in Ukraine. The paper is aimed at working out the system for assessing the educational constituent of the national economy innovative development, which is to ensure an effective state regulation of educational processes as well as to prevent the risks of reducing the educational security of the national economy. The study is performed by way of applying such general scientific methods as those of systemic and complex analyses, research of indicators values' dynamics, system generalization, statistical methods and the method of taxonomic analysis. As a result of using these methods as well as on the basis of a multidimensional analysis of educational indicators of the national economy innovative development, in particular of the international practices of educational and scientific breakthroughs, the authors advance and substantiate the measures necessary for the effective state regulation of educational processes.

1 INTRODUCTION

The ongoing processes of globalization, an intensive scientific and technological progress taking place on the basis of artificial intelligence development, information technology and transdisciplinary scientific knowledge, increase in the interpersonal and inter-organizational competition that characterize the present-day global economic system, etc. change dramatically not only economic processes but also the individual's role and place in them as well as the nature of the person's relationships with other participants of these processes.

Thus, modern society is on the verge of the fourth industrial revolution, which embraces the process of formation of the society of knowledge and of the Industry 4.0 (Kobets and Yatsenko, 2019), where the total digitalization is accompanied by the emergence of new professions that require new knowledge and skills, and, consequently, innovative approaches to education and human resources development. Clearly, in order to make an industrial breakthrough 4.0, humanity must first secure an educational breakthrough based on the new Education 4.0 system through implementation of the 4th Sustainable Development Goal: "Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all" as defined by the UN in 2015.

2 LITERATURE REVIEW

The processes of formation and development of the Education 4.0 system should be based, in our opinion, on the provisions of innovation theory, the notion of knowledge-based economy, the theory of life-

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long learning (LLL), of knowledge management, self-study and other present-day theories and ideas.

Defining the knowledge society, Kok (Kok, 2004) remarks that this notion encompasses all the aspects of human activities beginning from high-tech production up to artistic professions like in media and architecture, where knowledge is provided as the basis for added value creation. In his turn, Leiber (Leiber, 2018), while considering the knowledge society, emphasizes the crucial role of the quality of education in general and that of higher education viewed as a social, economic and environmental factor. Agrawal et al. (Agrawal et al., 2021) highlight a high correlation between information communication technology (ICT) and knowledge management. Valero and Van Reenen (Valero and Van Reenen, 2019) prove that increases in the number of universities are positively associated with future growth of GDP per capita. Supporting this view, Benešová and Tupa (Benešová and Tupa, 2017) underline the impact of technology not only on the emergence of knowledge-intensive products and services, but also emphasize its much greater impact on people's education in general. After all, only highly qualified and highly educated specialists will be able to control these technologies. It is clear therefore the increasing role of organizational education to adapt the people to changes that occur as a result of technological and economic innovation. The paper (Engstrand and Enberg, 2020) explores the role of relational power and discursive positioning in the knowledge integration process using a definite interdisciplinary project as an example and thus emphasises the necessity of carrying out more research that explicitly explores power in the knowledge integration process.

Thus, recent research (Thakur and Arora, 2022; Mane and Miravet, 2016; Marchiori et al., 2022; Kucherova et al., 2021) has shown that human capital makes a significant contribution to economic growth and technological development primarily through education, innovation and continuous growth. At the same time, the limited development of human capital leads to the use of natural resources as the main source of income, thereby reducing the level of the countries' economic development. In addition, the relationship between human capital and innovation at the country level is based on the fact that various forms of capital can be converted into resources and other forms of economic benefit. However, it is only a properly qualified human capital that can ensure the industrial and technological development of the country as well as can serve for its economic growth. Therefore, the assessment of education through the prism of country's innovative development, in our opinion, should definitely include indicators of the level of development of the country's human capital.

Nedelko et al. (Nedelko et al., 2019), as a result of studying the strategies and tools for knowledge management in innovation and Industry 4.0, emphasize that the use of the notion of knowledge management in Industry 4.0 should not only be encouraged but rather necessitated. It is well known that for the emergence of new knowledge and its commercialization, which is the essence of innovation, it is necessary to ensure close ties between industry and science and education (Trofymenko et al., 2021). Thus, we can state that education and science today are the starting point and the driving force to ensure the innovative development of business and, consequently, of national economies.

Considering the above-mentioned tendencies, the issue of measuring the effectiveness of educational process in accordance with the dynamic global socio-economic environment has become quite acute. There are a number of scientific papers substantiating the indicators of education performance for individual countries (Braunstein et al., 2022; Riley and Nuttall, 1994; Csomós, 2020) as well as methodologies presented by various international organizations, which include educational indicators (IMD - International Institute for Management Development, 2022; Dutta et al., 2020; Schleicher, 2019; UNDP, 2019; WorldBank, 2021; Schwab, 2018). However, given the urgent need to reform education within the process of Industry 4.0 formation, there is a necessity to search for new approaches to assessing educational indicators through the prism of their impact on the innovative development of the state, which will serve the increase in the efficiency of public administration and control.

Therefore, this paper is aimed at working out the system for assessing the educational component of the national economy innovative development, which will ensure the effective state regulation of educational processes as well as will prevent the country form the risks of reducing the educational security of the national economy. Accordingly, the main issue of the study is the definition and analysis of educational indicators, and the formation of recommendations on the development of educational indicators at various levels of state policy to ensure innovative development of the economy based on the study of effective global practices. The hypothesis lies in the idea that the growth of the indicators of education quality will lead to an increase in the metric of state innovative development.

3 METHODS

In the course of the study the authors employed general scientific and statistical methods, as well as the method of a taxonomic analysis. As is known, a multidimensional statistical analysis is used to determine the largest number of features that will affect the object of study. That is why to define the degree of a cumulative impact of the factorial characteristics on the level of the national economy innovative development, the authors offered to apply the taxonomic method. The necessity to opt for this method is born out of the demand to search for a single integrating indicator out of the large number of indicators that characterize innovative development, which allows increasing the efficiency of public administration and control (Ilyash and Stefaniak, 2012).

As the data base for the use of a taxonomic analysis we chose the educational indicators of innovative development of the national economy of Ukraine as of the years 2013–2019. Such indicators include the Human Development Index (HDI), the level of expenditure on education of GDP, the Education Index, the literacy rate (i.e. expected years of schooling), and Ranking of national higher education system.

Thus, the human development index is a combined index and an indicator of the educational component of the country's innovative development (WorldBank, 2021). The index measures the country's achievements in terms of life expectancy, access to education, actual income of the citizens, and takes into account changes in the indices of socio-economic and gender inequality and multidimensional poverty. In addition, the human development index is adjusted by political, economic, social, and environmental factors, such as: human rights and civil liberties, participation in public life, social security, the degree of territorial and social mobility of population, the level of cultural development, access to information, health, unemployment, crime, environmental protection, environmental impact and others. It should be mentioned this index comprises the following data: the acquired human capital; the expected duration of children's education at school; results of the standardised testing of schoolchildren; the percentage of adult survivors and the proportion of children without any developmental disorders (UNDP, 2019).

The literacy level of the country's population (expected time of schooling) is set by authors as a separate indicator of educational development because it indicates the general educational level of the population.

The education expenditures is one of the key indicators of innovative development. Innovative development of the domestic economy and strengthening the social component of state economic security can be ensured only by increasing human capital expenditures. Investing in education is a vital means of increasing human capital and prospects of the country's economic growth. Therefore, the level of expenditures on education of GDP was chosen as one of the indicators for taxonomic analysis.

The Education Index, which is a sub-index of the Human Development Index, should be also included to the educational indicators.

It is the economic development and competitiveness of the country that serve as the indicators of the country's economic security and largely depend on the number of educated and competent professionals, as well as technologies that increase their productivity. The higher education sector contributes significantly to realisation of these needs. In addition, in the modern world of alterglobalism, those high-quality higher education systems, which have broad links at the international level and contribute to the country's global development through the exchange of students, researchers, projects and ideas, demonstrate a high level of national economy. Therefore, one of the indicators of the educational component of the state innovative development at the global level is the ranking of national higher education systems (U21 Ranking of National Higher Education Systems) which enables assessing the overall higher education system of different countries at various stages of economic and social development (Williams and Leahy, 2020).

To conduct a taxonomic analysis of the educational component of innovative development, it is rational to perform a sequence of the following methodological steps (Ilyash et al., 2021):

- to form a matrix with the initial data necessary for the study of educational indicators of innovative development;
- to standardize the values of the indicators matrix;
- to form a reference vector representing the growth of the innovative development component under study;
- to calculate the distance between individual variables and the reference vector; item to define the taxonomic indicator of innovative development.

In accordance with the outlined algorithmic steps, it is expedient to form an observation matrix based on the input data. It should be mentioned that in our study the units (I_i) are represented by the innovative development educational indicators. Within the scope of these indicated we single out the educational component of innovative development (E), while the years sand for characteristic features.

The construction of the matrix respresenting the initial data by components comprises the following steps:

The first step presupposes the use of $I^{(E)}$ for the matrix in order to reveal the educational component of innovative development (size 5×7).

At the second stage, since the indicators of innovative development have different measurement units, it is necessary to form a matrix of standardized values. This procedure is performed by replacing the criteria values with the coefficients standardized indicators (Ilyash and Stefaniak, 2012) according to the following formula (1):

$$Z_i = \frac{I_i}{\overline{I}} \tag{1}$$

where:

I_i is the value of the i^{th} indicator;

$\overline{I}$ is the average value of the i^{th} indicator.

After indicators' standardization, to carry out a further taxonomic analysis, the features of the observation matrix are to be divided into those of stimulators and destimulators that determine the direction of the impact on the national economy innovative development. In this case, stimulatory factos have a positive effect on the development level, while destimulatory factors restrain.

Differentiation of the studied factors into stimulating and destimulating ones is given in the table 1.

The division of the indicators into stimulators and destimulators can serve as the basis for finding out the ideal reference vector and forming the values of the indicators (Ilyash and Stefaniak, 2012) in the following way:

$$\begin{cases} I_{oi} = \max I_{ij} & (stimulator) \\ I_{oi} = \min I_{ij} & (destimulator) \end{cases} \tag{2}$$

After that, we receive a vector-standard of the innovative development level within the framework of educational component. To calculate the integrated taxonomic index, it is necessary to find the average distance ($\overline{C_0}$), the mean value of the square root of the average square of the difference of values of characteristics (S_0), deviation of the distance between the point-unit and the upper pole point from the value of characteristics distance (d_i) for the educational component of innovation development according to the following formulas (3-6):

1) average distance:

$$\overline{C_0} = \frac{1}{m}\sum_{i=1}^{m} C_{i0} \tag{3}$$

where:

m – the number of periods;

C_{i0} – the distance between the point-unit and the point E_{M4};

2) the mean value of the square root of the average square of the difference between the values of characteristics:

$$S_0 = \sqrt{\frac{1}{m}\sum_{i=1}^{m}(C_{i0} - \overline{C_0})^2} \tag{4}$$

$\overline{C_0}$ – the average distance;

C_{i0} – the distance between the point-unit and the point E_{M4};

3) deviation of the distance between the point-unit and the point the reference vector from the value of characteristics distance:

$$C_0 = \overline{C_0} + 2S_0 \tag{5}$$

$$d_i = \frac{C_{i0}}{C_0} \tag{6}$$

where:

S_0 – the mean value of the square root of the average square of the difference of values of characteristics;

C_{i0} – the distance between the point-unit and the point E_{M4};

C_0 – the distance.

On the basis of the obtained results, we can define the taxonomic indicator of the level of the system economic security by the following formula (7):

$$K = 1 - d \tag{7}$$

where:

d – deviation of the distance between the point-unit and the point E_{M4} from the value of characteristics distance.

Thus, the obtained indicator can acquire higher values with the higher values of stimulants, and, consequently, lower ones with low values of stimulants. By calculating this indicator, we will be able to analyze the directions and scales of changes that occur in the system under study, in particular, in the innovation system of the national economy on the basis of one synthetic feature of the educational component.

4 RESULTS

For the innovative development of the national economy, the development of human capital assets undoubtedly remains the driving force. That is why the study of educational and scientific direction of innovative economic development, which is the basis for ensuring the capital development, is of an urgent need. At present, the model of education aimed at

Table 1: Educational indicators of innovative development (stimulator / destimulator).

Symbol	Indicator	Stimulator or destimulator
E	Educational component	
I_1	Human Development Index	Stimulator
I_2	Level of expenditures on education of GDP, %	Stimulator
I_3	Education index	Stimulator
I_4	Literacy rate of the country's population (expected years of schooling)	Stimulator
I_5	Ranking of the national higher education system	Stimulator

training highly qualified industry personnel is almost completely lost, while industrial enterprises cannot function efficiently with a shortage of specialists having an up-to-date training. In order to preserve the industrial potential, the structure of innovative education should form a symbiosis of higher education institutions, research institutes, production facilities of industrial enterprises and public authorities. However, the majority of organizations cannot make the use of human capital resources since they are limited by the approaches aimed at performing specific tasks rather than being focused on research and development. At the same time, industrial enterprises agree that managing human capital development is one of the priorities of innovation progress.

Unfortunately, in Ukraine there is a significant gap between the knowledge and competencies of the students who graduate almost without any practical experience, forcing employers to spend time preparing them for a particular job (Kahkonen, 2018; Bhattacharya, 2017). To build innovative human capital, the educational system should include more practical skills, in particular through the integration of business into the educational process, and, thus, provide the generation-to-come with the up-to-date theoretical and innovative practical tools.

The research results of the different countries' experience on the development of education are given below.

In particular, such countries as Singapore, China, India, South Korea, USA, Japan, Finland, Brazil, and others demonstrated the educational breakthrough achieved through high quality STEM education, due to increase in expenditures on education, by means of supporting fundamental research and a number of programs aimed at developing the level of general public digital competence as well as thanks to the growth in patent productivity in priority sectors of the economy.

Singapore, for instance, has introduced programs to set up technical schools and international corporations to train unskilled workers in the spheres of information technology, petrochemistry and electronics. The strategy of involving Singapore's multinational organizations in training its workforce has contributed in the long run to the country's economic prosperity. As a result of the education system reform taken place in Singapore, minimum compulsory educational standards have been introduced for all schools, English has become an obligatory discipline for all types of schools and a number of other subjects are tought in English. The government is constantly investing in the education of Singaporean students in the best universities world, while creating at the same time leading research and educational centers in Singapore. Distinguished results in education have been achieved due to implementation of the Plan of Research and Innovation Enterprises completed by 2020 (Research, Innovation and Enterprise Secretariat, 2016).

China's economic reform program was based on lowering government norms on prices in education sphere and increasing investment in education of personnel (Santacreu and Zhu, 2018).

India initiated a policy of promoting the quality of the workforce. The introduction of the language law made English a second national language, which contributed to the growth of the country's technological development and signing international agreements with the leading companies in the IT sector.

South Korea, the USA, Japan, and China have the policy of increasing the share of GDP in research and development (R&D), which results in the growth of intensity and quality of research and development (World Bank, 2019).

In Finland, there are programs to expand cooperation with foreign experts since due to the aging of its population in some industries, there is a shortage of workforce. There are also programs aimed at financial support of innovations in R&D. One euro invested in innovation for research brings about 10-20 euros net profit, which corresponds to 70% of investments (compare, for example, in Russia they spend 10% of investments, while in France 90%).

In Brazil, there is the Bolsa Familia Income Transfer Programme (Family Assistance), which provides

monetary benefits to families who send their children to school. The government has also introduced the policy of increasing investments in education to strengthen human resources.

It seems inevitable that automation, digitalization and other forms of technology will put an end to millions of jobs and will create new opportunities for the workforce. At the same time, it is of vital importance to prepare the next generation of workers to participate in the development of Industry 4.0. It is education that should be the driver of future skills by means of going beyond the traditional teaching, including entrepreneurship, soft leadership, technology and workforce readiness. Accordingly, it proves the need to provide such the condition for the development of human resources required to meet the changing demands of the twenty-first century as the improvement of quality of primary schools education.

Since the adoption of the Universal Declaration of Human Rights in 1948, countries have been making efforts to universalize primary education. However, the quality of education is going down due to the low quality of primary education. Thus, in 2019, Ukraine demonstrates the lowest level of quality of primary education as compared to the world's leading countries. The percentage of students with the highest results in at least one field (reading, mathematics, and natural sciences) is only 7.5%, which is from three to five times lower than in China (49.3%), Singapore (43.3%), South Korea (26.6%) and Canada (24.1%), while it accounts for 50% of the quality of primary education in Denmark (15.8%). Some of the advantages of high quality primary education in Singapore and South Korea comprise effective leadership, quality teacher advanced training, high salaries for teachers, teachers' professional development strategy, a high percentage of modern equipment supply, the ability to work with innovative interactive technologies as well as social security of teachers (Schwab, 2018). In the USA, the Regional Councils for Economic Education and the State Federal Reserve offer the teachers an annual weekly summer training program based on the model "Key to Financial Success". A comparison of the main indicators of the educational and scientific breakthrough of Ukraine with countries of progressive development in 2019 is presented in the table 2.

Over the last two centuries, alongside the increase in the number of students acquiring primary education, there has been a steady increase in the level of literacy of the world population. However, in some African countries, the literacy rate among young people is still below 50.0%. According to the level of population literacy, Ukraine ranks 51st in the world ranking of competitiveness. Thus, the average number of years spent on studying and the expected duration of education in Ukraine is 10,4 years, which sets it ahead of China (7,8 years) by 2,6 years and below Germany (17,1 years), Canada (13,8 years) and the United States (13,4 years). Among the possible threats of insufficient literacy in Ukraine's population, to name but a few, are the state's non-recognition of other than official forms, formats and methods of training, lack of the culture of dual education within the framework of labor relations, lack of employers' interest in financing employee training, the employees' insufficient practical and soft skills (Karpenko, 2015).

As for the education in Japan, it is almost 32% funded by private sources. The education in Denmark is entirely funded by Danish government which guarantees free education for all (World Bank, 2019). In the Netherlands and other countries of Northern Europe, the government has developed programmes to provide opportunities to participate in formal and / or informal education for adults and the unemployed (64% and 57% of adults and the unemployed have already participated in these programmes).

A feature of the national education system is a relative high level of funding, i.e. the maximum amount of expenditures is allocated on education. Thus, the indicators of education financing in Ukraine in 2019 exceed the average indicators of the OECD countries (by 6% of GDP) (Zhylinska et al., 2017), in particular Denmark (6,5% of GDP), the United States (6%), Finland (5,7%) and are 2,5 times higher than in Singapore (2,7%), Japan (3,2%), and China (3,6%). A common feature of the leading countries in terms of financing higher education with the insignificant level of public sector spending is a high share of of funding provided by the private sources, in particular, in the United States – 26%, Australia – 23%.

Digital competencies of the population play quite an important role in the educational and scientific breakthrough (Bondarchuk et al., 2022). However, as of 2017, according to the Digital Skills Index of the European Digital Economy and Society Index (DESI), almost half (44,0%) of the EU population does not have the necessary skills to use digital technologies (Russo, 2020). To ensure an educational breakthrough in Ukraine, the Digital Agenda of Ukraine – 2020 was adopted with an aime to use digital technologies, create a digital society and ensure the competitiveness of the country and its citizens. Thanks to digitalization, Ukraine is able to reduce the gap in international indicators of competitiveness (Kuybida et al., 2019), since in 2019 it ranked 56th with the index 4,5 economic units (EU) and as compared to 2016 it increased the level by only 8

Table 2: Indicators of educational breakthrough in Ukraine and the countries of progressive development in 2019 (based on (WorldBank, 2021; UNDP, 2019; IMD - International Institute for Management Development, 2022; Schwab, 2018)).

Indicators	Ukraine	Finland	Germany	Denmark	USA	Canada	Australia	South Korea	China	Singapore	Japan
Quality of primary education (% of students with the highest results in at least one of the disciplines: (reading, mathematics, natural sciences, level 5 or 6)	7,50	21,00	19,10	15,80	17,10	24,10	18,90	26,60	49,30	43,30	23,30
The literacy level of the country's population (the average number of years spent studying) and the expected duration of education	10,40	17,10	12,40	12,60	13,40	13,80	12,40	12,10	7,80	11,90	12,80
Index of digital competencies of economically active population	4,50	5,10	5,80	5,40	5,30	5,10	5,00	5,00	4,70	5,60	4,40
Expenditures on education, % of GDP according to IMD data	6,00	5,70	4,10	6,50	6,00	4,40	5,00	5,00	3,60	2,70	3,20

points. The leading countries are Finland (5,8), Singapore (5,6), Denmark (5,4) and the United States (5,3). With the support of the National Library Council and the Singapore Cybersecurity Agency, curricula have been updated with a view to providing better cybersecurity awareness and acquiring skills to detect fake news and protect onself against it. Besides, the government introduced a route map of teaching technology intensity, which is a three-year plan to help small and medium-sized enterprises (SMEs) accelerate technology implementation and help the population expand their digital capabilities (e.g., a Memorandum on cooperation between SkillsFuture Singapore and Microsoft has been signed aimed at helping make profit for 5000 people and 100 small- and medium-sized enterprises). Denmark has developed the Digital Literacy Manifesto, which has inspired politicians to reflect on digital skills and transformation.

We shall remark here that the process of monitoring the educational component of innovation development should be carried out within the system of indicators: correlation between the level of education expenditures to GDP, human development index, education level index, literacy level and the rating of the higher education system. The system of the mentioned indicators is presented in the table 3.

According to the report submitted by UNDP in 2019, Ukraine ranked 74th in the human development index among 183 countries surveyed. Given the significant part of the population with higher education (82%), Ukraine has an average human development index among European countries, which is 0,779 points. At the same time, the share of people engaged in scientific activities is only 0,34% out of the total employed population.

It should be added that 66 countries of the world belong to the category of high level of human development, among which: Switzerland (2nd place, 0,955 points), Germany (6th place, 0,947 points), Great Britain (13th place, 0,931 points), Canada (16th place, 0,929 points), Estonia (29th place, 0,892 points), Lithuania (34th place, 0,882 points), Poland (35th place, 0,880 points), Romania (49th place, 0,828 points), Kazakhstan (51st place, 0,825 points), Russia (52nd place, 0,824 points), Belarus (53rd place, 0,823 points), Turkey (54th place, 0,820 points), Bulgaria (56th place, 0,816 points), Georgia (61st place, 0,812 points), Serbia (64th place, 0,806 points).

The World Bank estimates the human capital index in Ukraine at 0,63 points, so Ukraine ranks 50th among 157 countries. Thus, a child born in Ukraine can rely upon acquiring only 63% of the potential level of human capital, being possible only under condition of receiving complete education and having a good health. In terms of figures, Singapore (88%), Hong Kong (81%) and Japan (80%) have been ranked first for several years in a row. The top ten countries also include South Korea, Canada, Finland, Macau and Sweden (about 88%), Ireland and the Netherlands (79%). The lowest positions in ranking are occupied by the CAR (29%), Chad (30%) and South Sudan (31%).

The comparison of the index of human capital with GDP per capita in the world allows us to trace

Table 3: The rate of change of the educational component indicators signifying the innovative development of Ukraine within the period of 2013–2019 (based on (WorldBank, 2021; UNDP, 2019; IMD - International Institute for Management Development, 2022)).

No	Indicators	Years							Growth rate, %		
		2013	2014	2015	2016	2017	2018	2019	2019/2018	2019/2015	2019/2013
Educational indicators											
1.	Human development index	0,74	0,75	0,74	0,75	0,75	0,75	0,77	102,67	104,05	104,0
2.	Level of education expenditures to GDP, %	5,90	6,20	6,70	6,70	6,00	5,90	5,00	84,75	74,63	84,75
3.	Education level index	0,791	0,8	0,791	0,792	0,794	0,792	0,799	100,88	101,01	101,01
4.	Literacy level of the country's population (expected time of schooling)	14,90	15,00	14,90	15,10	15,10	15,10	15,10	100,00	101,34	101,34
5.	Ranking of the national higher education system	49,9	43,9	44,0	42,1	47,7	47,4	45,1	95,15	102,50	90,38

the correlation between the level of the country's economic development and the level of education received by human capital (figure 1). Thus, in general, the countries with the highest human capital index have higher GDP per capita: Singapore (0,88 and 652333), Japan (0,80 and 40246), Canada (0,80 and 46194), Finland (0,80 and 48782), Switzerland (0,80 and 51615), Ireland (0,79 and 78660,96). The lowest positions are occupied by Congo (0,37 and 553), Yemen (0,37 and 774), Rwanda (0,38 and 820), Ethiopia (0,38 and 855), Burundi (0,39 and 261). It should be added that in 2019 the value of the human development index in Ukraine was 0,63, while GDP per capita amounted to 3656 (UNDP, 2019).

The total amount of education funding (from public, local and private sources) varies from 5,0% to 6,7% of GDP and is characterized by declining dynamics. Although the Law of Ukraine "On Education" states that education funding should comprise at least 7% of GDP, in 2019 the amount of financial support in this area was only 5,0% and the share of expenditures on education in the budget of Ukraine comprised 17,1% (State Statistics Service of Ukraine, 2021). Examining the dynamics of this indicator changing throughout 2014–2019, we can single out two periods: the 1st period of 2014–2016 is marked by a decrease of 3,6 percentage points, while the 2nd period (2016–2019) is characterised by an increase of 1,6 percentage points.

We should also point out that starting from the year 2015, the consolidated budget expenditures on education in GDP have also been decreasing. Thus, despite its unstable dynamics, expenditures on education as a percentage ratio of GDP amounted to 6,1% in 2019, while in 2016 it was 5,4%, which is 0,9% lower than in 2014. At the same time, it should be noted that in comparison with the EU countries, Ukraine spends much more on education. Thus, the total expenditure on education from GDP in Poland is 4,6%, in Latvia – 4,7%, in Italy – 3,8%, Germany – 4,8%, Estonia – 5,2%, Switzerland – 5,1%, and Romania – 3,0%. The high level of expenditures on education in Ukraine is explained by the fact that the majority of Ukrainian higher education institutions are financed from the state budget (72%), while in other countries a significant share is made up of private educational institutions (43%).

Another key indicator of innovative development in the context of ensuring the economic security of the country is the Education Index, which is a subindex of the Human Development Index (WorldBank, 2021). The optimal value of the indicator for the developed countries is no less than 0,8 points. That is why in 2019 Ukraine occupied the 46th rank (0,797 points) which testifies a significant achievement of the country's population in education in terms of adult literacy and the total number of students receiving education. Figure 2 shows the general dynamics of the education index among other indicators comprising the educational component of innovative development considered within the analysed period.

The education index also allows estimating the average number of, as well as the expected duration of education of the population, which in Ukraine correspond to 11,4 and 15,1 years respectively. Leading positions in the world are occupied by Australia (22,0 years), Belgium (19,8 years), Sweden (19,5 years), Finland (19,4 years), Iceland (19.1 years), Denmark (18.9 years), New Zealand (18,8 years), Ireland (18,7 years), the Netherlands (18,5 years), and Norway (18,1 years). We will emphasise that creation of conditions for lifelong learning ensures the adaptation of labor capital to rapid technological changes, and, consequently, accelerates economic development and serves for the growth of national economy competitiveness.

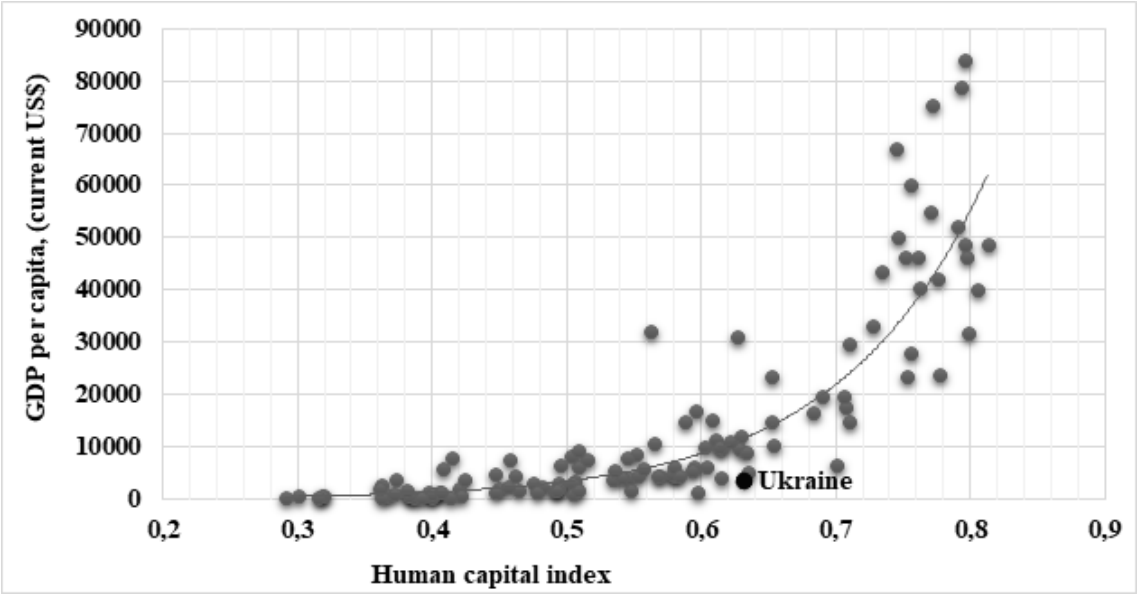

Figure 1: The ratio of the human capital index and GDP per capita of Ukraine and the world in 2019 (based on (UNDP, 2019)).

For instance, in 2020, Ukraine ranked 36th. If to evaluate this indicator in terms of its individual constituents, we can see that according to the degree of investments from both the private and public sectors Ukraine occupies the 27th place (52,6 points); as to the public policy and regulation as well as the possibility of acquiring education, Ukraine takes 39th place (70,6 points); according to the level of international cooperation, which demonstrates the degree of openness of the higher education system, Ukraine is at the 38th place (40,4 points); considering the quality of scientific research, scientific publications, compliance of higher education with the demands of the national labor market, including further employment of educational institutions' graduates, Ukraine occupies 42nd place with a score of 28,7 points. At the same time, the highest ranking include the USA, Switzerland, Denmark, Singapore, Sweden, Great Britain, Canada, Finland, Australia, the Netherlands, and Norway, where the overall indicator value is no less than 80 points.

It is worth noting that recently there has been a tendency to reduce the number of higher education institutions. Thus, in 2019, the Ministry of Education and Science of Ukraine granted the right to carry out activities in the field of higher education only to 281 educational institutions, which is 25% less than in 2010. A similar tendency is typical of the indicator "the number of students per 10000 of population", which during the last 9 years dropped 0,6 times from 476 to 302 students. The reasons for this negative tendency is the decrease in the birth rate, which, in its turn, led to a reduction in the number of university applicants and consequently in a number of students in 2019 by 63% as compared to 2010 (figure 3). Regarding the academic and teaching staff in the field of education, it should be mentioned that there are 14,25 students per teacher in secondary schools, and 10,75 students per one teacher in higher educational institution, which is 1,5 times lower comparing with the average indicator in the majority of economically developed countries.

As for education expenses, there has been a gradual increase in private sector expenditures on R&D (by UAH 177 billion or 66,6% within the period of 2013–2019), the following indices remain low: the levels of expenditure on education (5,0% of GDP in 2019 and a decrease by 0,9 percentage points by 2013), implementation of scientific and technical work (0,43% and 0,27 percentage points, respectively), ranking of the national system of higher education (45,1% and a decrease by 4,8 percentage points by 2013), the amount of scientific and technical work being realized (0,3% to GDP and a decrease by 0,17 percentage points by 2013) and specialists who perform scientific and technical work (0,48% out of the total number of employees and a decrease by 0,32 percentage points by 2013). It is also observed declining in the level of patent productivity, reduction in the number of specialists involved in R&D implementation, failing to maintain leading positions in public funding of scientific and technical work, budget funding including (State Statistics Service of Ukraine, 2021).

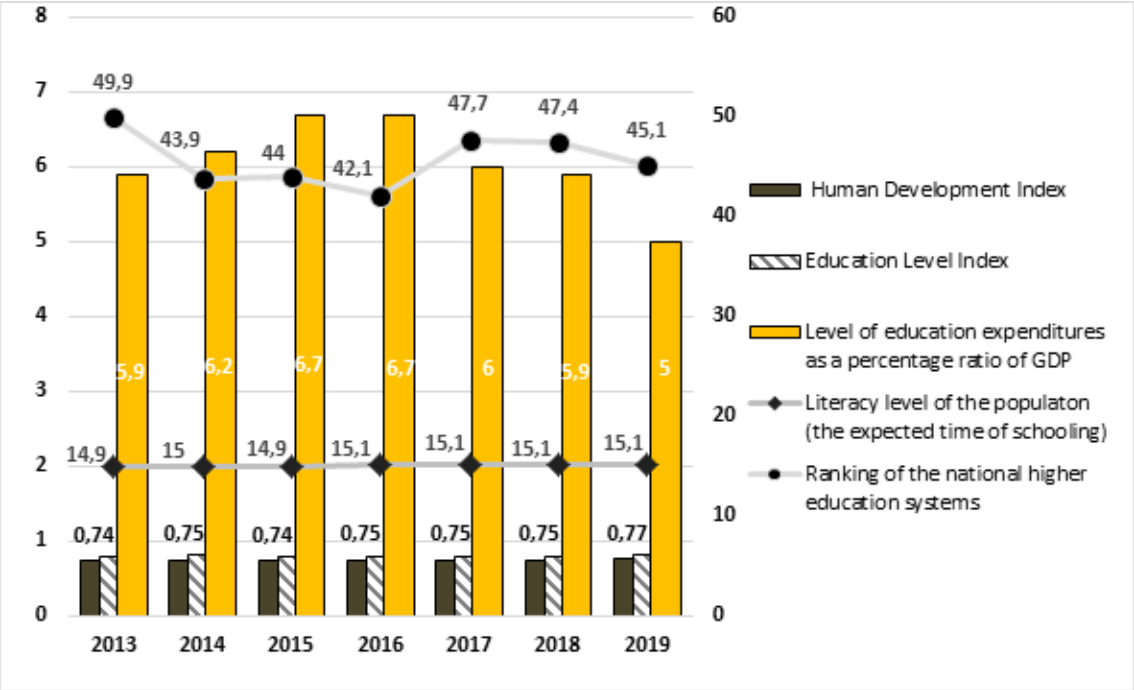

Figure 2: Changes in the education index within the system of indicators comprising the educational component of Ukrainian innovative development from 2013 to 2019 (based on (Williams and Leahy, 2020; UNDP, 2019; WorldBank, 2021)).

To overcome the negative phenomena in the field of education, it is necessary, first of all, to build the relevant skills and competencies in specialists-to-be through a STEM-oriented approach to teaching and learning (Le et al., 2021; Hrynevych et al., 2021). Thus, in the UK, to meet the demands for specialists in the STEM sphere it is necessary to have more than 100 thousand people graduate by 2020, while in Germany there is a shortage of 210 thousand workers in natural sciences, mathematics, technology and computer science. However, to ensure the dynamic development of the national economy, it is essential to either significantly increase the intellectual potential of STEM specialists, or there should be a transition of the economic development to a new phase with the use of technologies of a new generation (Kelley and Knowles, 2016). For the development of digitalization processes it is important also taking into account such world experience as Digital Competence Program, the Danish "Digital Literacy Manifesto" (Kuybida et al., 2019).

Thus, modernisation of the education system must be carried out taking into account the directions of the international economy development as well as defining the role and place of the country in the global dimension. With such an approach to the education system formation in a short period of time Ukraine will have had the trained personnel of necessary specializations.

After studying the above mentioned factors influencing education development in Ukraine as well as in other countries, we have applied the taxonomic analysis. First, we compiled a matrix of input data I^{M4}:

$$\begin{bmatrix} 0{,}74 & 0{,}75 & 0{,}74 & 0{,}75 & 0{,}75 & 0{,}75 & 0{,}77 \\ 5{,}90 & 6{,}20 & 6{,}70 & 6{,}70 & 6{,}00 & 5{,}90 & 5{,}00 \\ 0{,}79 & 0{,}80 & 0{,}79 & 0{,}79 & 0{,}79 & 0{,}79 & 0{,}79 \\ 14{,}9 & 15{,}0 & 14{,}9 & 15{,}1 & 15{,}1 & 15{,}1 & 15{,}1 \\ 49{,}9 & 43{,}9 & 44{,}0 & 42{,}1 & 47{,}7 & 47{,}4 & 45{,}1 \end{bmatrix}$$

The next step was the formation of a matrix of standardized values of Z^{M4}:

$$\begin{bmatrix} 0{,}99 & 1{,}00 & 0{,}99 & 1{,}00 & 1{,}00 & 1{,}00 & 1{,}03 \\ 0{,}95 & 1{,}00 & 1{,}08 & 1{,}08 & 0{,}97 & 0{,}95 & 0{,}91 \\ 1{,}00 & 1{,}01 & 1{,}00 & 1{,}00 & 1{,}00 & 1{,}00 & 1{,}01 \\ 0{,}99 & 1{,}00 & 0{,}99 & 1{,}00 & 1{,}00 & 1{,}00 & 1{,}00 \\ 1{,}10 & 0{,}97 & 0{,}97 & 0{,}93 & 1{,}05 & 1{,}04 & 0{,}99 \end{bmatrix}$$

According to the results of the chosen methodology application, we received the vector of the educational component being the standard of the level of innovative development within the framework of the educational component:

$$E^{M4} = (1.03; 1.11; 1.01; 1.00; 1.10)$$

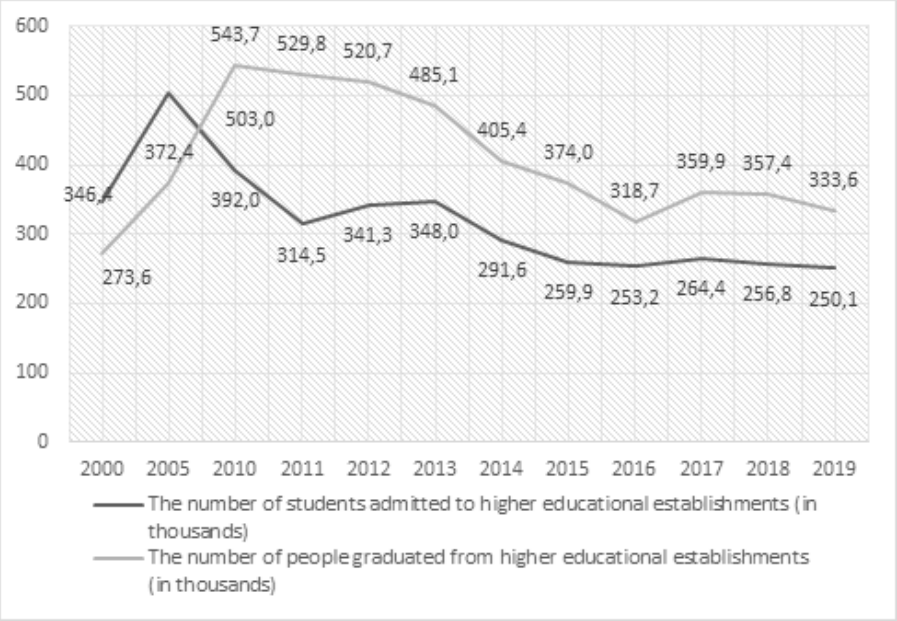

Figure 3: Dynamics of the indicators of higher education in Ukraine in 2000, 2005 and during the period from 2010 to 2019 (based on (Williams and Leahy, 2020; UNDP, 2019; WorldBank, 2021)).

At the next step of our research we calculated the taxonomic indicators of the educational component of the country's innovative development.

The closer the value of the taxonomic coefficient to one, the greater is the impact of a particular educational indicator on the national economy innovative development. The calculations of taxonomic indicators of the educational component of the national economy innovative development within the period from 2013 to 2019 are given in the table 4.

The taxonomic indicator's dynamics in the context of the educational component of the country's innovative development is shown in figure 4.

Despite the average value of the human development index of European countries, the taxonomic indicator of the educational component as a part of innovative development is characterized by a low share (0,008).

Thus, the taxonomic analysis of the educational component of the national economy innovative development proves its negative dynamics, which signifies the importance of taking into account the changes in educational indicators as well as timely response to these changes for the effective state regulation of the human capital development, which serves as the basis for the development of innovation and prevention from the risks of reducing educational security of the national economy.

5 DISCUSSION AND CONCLUSIONS

The developed in the paper advanced system for assessing the educational constituent of the national economy innovative development, performed on the basis of taxonomic analysis allows taking into account the main indicators of the educational development in the country, thus simplifying the analysis of their impact on the national innovation system and, thus, serves as an effective tool for finding optimal solutions in the state regulation of educational processes as the basis for innovative activities of all its participants.

As a result of the performed research, it was found out that the potential of the educational and scientific components of the national economy of Ukraine innovative development is not realized to its full. These results elucidate the reasons for Ukraine's weak position in the state innovative economic development, at present being one of the most important factors of economic security. Therefore, judging from the research results, in order to guarantee the national economy innovative development, the primary task is to ensure the growth of taxonomic indicators within the educational component.

In particular, the lack of systematic managerial decisions by state authorities in solving problems of educational policy development requires scientific research to put forward proposals and set primary func-

Table 4: Values of taxonomic indicators of the educational component in the system of the country's economic security within the period from 2013 to 2019.

Title	Indices	Years							Values
		2013	2014	2015	2016	2017	2018	2019	
Educational component (M4)	$C_{i0}^{(4)}$	0,139	0,157	0,136	0,173	0,128	0,146	0,300	$\overline{C_0} = 0,179$
	$d_i^{(4)}$	0,499	0,564	0,488	0,620	0,459	0,522	0,992	$S_0 = 0,055$
	$K_i^{(4)}$	0,501	0,436	0,512	0,380	0,541	0,478	0,008	$C_0 = 0,279$

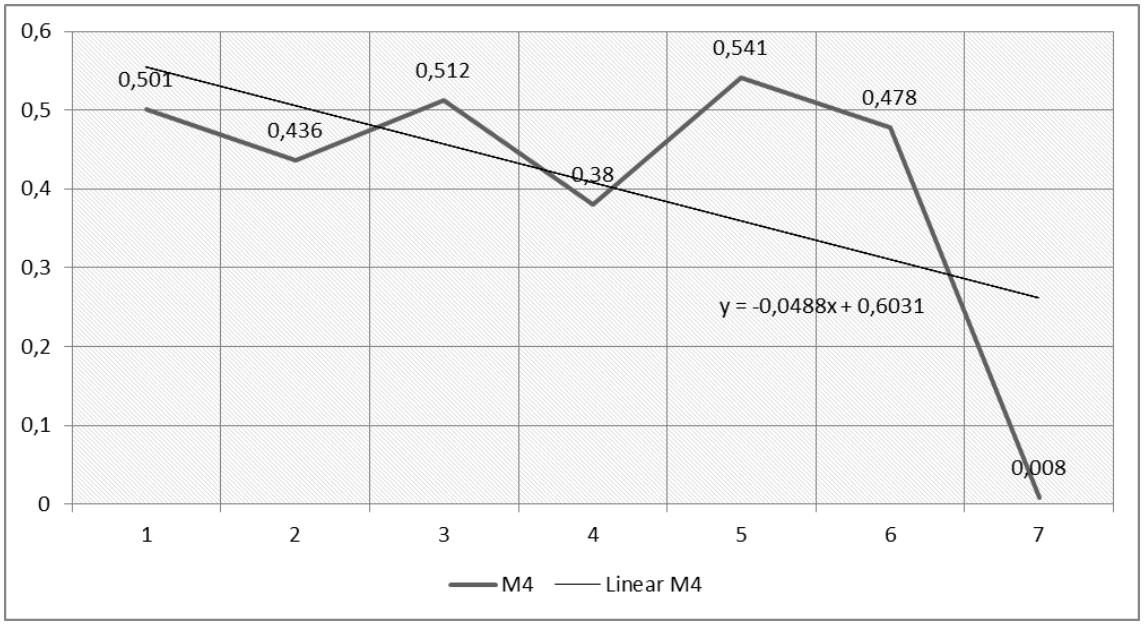

Figure 4: Dynamics of the taxonomic indicator of the country's innovative development (from a perspective of an educational component) within the period from 2013 to 2019.

tions of corresponding ministries and agencies in order to ensure the innovative development of the national economy. According to the results of the present study the primary functions of the state policy to ensure growing of the educational component of the national economy innovative development have been defined. In particular, at the level of the Ministry of Education and Science of Ukraine it is expedient to introduce the Strategy of accelerated formation of the teachers' educational potential. This will contribute to the spread of innovation in the education system of Ukraine in the context of global digitalization. Based on the high indicators of education in Japan, Denmark and the Netherlands obtained in the process of the conducted research and taking into account the directions of their development,it is advisable to introduce the programs of learning English as a first foreign language into primary school; to develop, in cooperation with private educational institutions, educational programs aimed at introducing up-to-date teaching methods and programs to provide the opportunities for adults and the unemployed to take part in formal and / or informal education. A number of programs should be initiated to start technical schools and fee-paying international corporations to train unskilled workers in the field of information technology, petrochemistry and electronics (those who could not get industrial jobs, the government could increase the number of labor-intensive retail services such as in the sphere of tourism and transport). Taking into account the analysis of the development of human capital, it is advisable to take the experience of Singapore as a basis,and to recommend to develop a Strategy for Involving Multinational Organizations in Labor Training in Ukraine, and to work out a Strategy for uniting the country's largest technical universities with the purpose to develop advanced clusters for the research of future technologies and ensure the presence of the association members in public, political and economic circles to warrant a high level of training of future personnel.

At the level of the Department of Scientific and Technical Development and the Ministry of Economy of Ukraine it is worthwhile to introduce a New Plan

for the Development of Research Innovative Enterprises until 2025, that allows to take into account the successful USA experience.

At the level of the Ministry of Finance of Ukraine, alongside the Ministry of Economy of Ukraine, it is important to assist small and medium enterprises (SMEs) in accelerating technology implementation and helping the population expand its digital potential.

At the level of the Cabinet of Ministers of Ukraine it is expedient to introduce Programs of funding educational institutions regardless of the form of ownership, to develop an effective formula of mixed financing in various proportions, which implies a gradual reduction of state funding while increasing the share of private funding (Singapore experience), to stimulate government to invest in the education of Ukrainian students in the best universities in the world, while creating leading research and educational centers at home.

At the level of the Ministry of Digital Transformation of Ukraine, it is recommended to introduce an online resource with a view to increasing the digital competence of citizens, following the example of Digital Competence. The introduction of the analogue of such a program will give impetus to digital initiatives, the increase in digital competencies of Ukrainian citizens as well as the use of the Danish "Digital Literacy Manifesto", which will stimulate the development of digital skills and critical thinking.

Implementation of the suggested measures within the framework of achieving educational and scientific breakthrough will allow to increase the overall indicator of the educational component in order to ensure the national economy innovative development.

The limitations of the study are impossibility to take into account the state of education in Ukraine during the war. In our opinion, the deterioration of the state of the educational component of the state's innovative development is expected and obvious. Among the positive expected educational trends is the growth of digital literacy of the population and the development of new technologies. Therefore, the study of the educational component and the development of mechanisms to ensure its strengthening in the post-war period will be an important and priority area of the future research.

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Empirical Evidence of Intangible Assets Improve the Financial Performance of Slovak ICT Companies

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Keywords: Intangible Assets, Intellectual Capital, Financial Performance, ICT Companies.

Abstract: In the conditions of the knowledge economy, the financial performance of high-tech enterprises largely depends on the efficiency of the processes of creating and using intangible assets. To increase it, it is necessary to build an effective intangible investment policy, which should be based on an understanding of the role of certain types of intangible assets in increasing financial performance. The hypothesis of the study is the existence of a significant positive impact of intangible assets on the financial performance of ICT companies. A sample of 180 Slovak ICT companies for the period 2015–2019 has been investigated. The primary research method was the regression analysis of panel data, which was carried out using the GRETL software package. Four regression models were formed based on using such dependent variables as Return on Assets, Net Profit Margin, Assets Turnover, and Return on Equity. Each of the selected models included eight independent variables – Research and Development Intensity, Research and Development Intensity Squared, Software, Intellectual Property Rights, Acquired Intangible Assets, Leverage, Size, and Dummy variable for ICT sub-sectors. For each of the models, an estimate panel data parameter was chosen based on the F-statistics test, Breusch-Pagan test, and Hausman test (Model 1-3 – Pooled OLS model, Model 4 – Fixed Effects Method). Adequacy of each of the models to the generated data was checked on the basis of the Normality test, Autocorrelation test (Wooldridge test for autocorrelation), and Heteroscedasticity test (White test, Wald test). The hypothesis of the study was partially confirmed, since only RDI, RDI2 and AIA have a significant positive impact on the financial performance of Slovak ICT companies. The strength and direction of influence of independent variables vary depending on the indicator characterizing financial performance. Only the independent variable AIA has a permanent inverse effect on all indicators of financial performance of Slovak ICT companies. It was established that the level of influence of control variables on indicators of financial performance is partial and multidirectional, and applies only to certain types of them.

1 INTRODUCTION

Over the last three decades, a significant number of scientists have been actively discussing the change in the role of different types of capital in the process of creating economic value of enterprises and ensuring their sustainable and long -term success. In particular, it is reminded on the determining role of intellectual capital in this process by shift in the "production mix" and management's focus, moving from the industrial focus (of capital and labour) to intellectual capital and trade in ideas, based on intellectual property rights, especially patents for its connection to technology (Daum, 2002; Abeysekera, 2008; Moberly, 2014; Ullberg et al., 2021). Under these conditions, the value of enterprises and their profitability become more dependent on their ability to effectively realize their existing innovative potential and to use their capitalized

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intangible assets. This issue is even more relevant in the period of overcoming the consequences of the COVID-19 pandemic and in the context of the introduction of a proactive sanctions policy of world leaders, which results in a reduction in trade in traditional goods and services, given the growth of the market of unique intellectual technologies, which ensure the formation of a stable value for enterprises.

In such new conditions, the economy of developed countries becomes increasingly dependent on the development of national intellectual capital. And for a large number of enterprises their financial performance depends on the effectiveness of implementation of the policy on creation of new and use of available intangible assets, ensuring their incorporation into the activity of the enterprise, the establishment of their effective partnership, stewardship and control. At the same time, the activity of enterprises under such conditions is characterized by frequent occurrence of network effects, high probability of occurrence of market and technological risks, which provides the necessity of rethinking their business strategies, which will include realization of strategic initiatives on intangible values. This is especially relevant for high-tech enterprises, whose activity is characterized by high level of usage of intangible assets and is aimed at creation of innovative technological products and services.

The presence of such economic changes in the global business environment makes it necessary to search for new theories and policies that would enable the scientific substantiation of decisions and behavior of management of companies with a high share of intangible assets used in the process of development and design of technological products and services to ensure their strong financial performance.

To determine impact of impossible assets on companies performance, the activity of Slovak companies from information and communications technology (ICT) sector was analyzed. Such enterprises, which relate to processes of processing, storage and transfer of information, production of computers and telecommuting devices, and also provision of related services, belong to high-tech enterprises, the process of creating value in which depends to a large extent on effective use of intangible assets. Investing in high-tech intangible assets of ICT sector enterprises should lead to the improvement of their financial indicators. However, as the studies Huňady et al. (Huňady et al., 2019), Slovakia still has only very small proportion of business R&D in ICT sector. This is evidence of the cautious policy of Slovak ICT companies to implement intangible investments as a result of the existence of significant risks and uncertainty as to the return of such investments. Therefore, in order to minimize such risks and eliminate uncertainty, in order to build an effective intangible investment policy at ICT enterprises need to identify features of relations between different types of intangible assets and different financial performance indicators.

In the Slovak Republic over the past ten years, there has been active development of the ICT sector. In particular, the number of employees involved in the information and communication technology services sector in Slovakia increased from 28905 in 2009 to 53676 in the 2019 year (SARIO, 2021). This shows an increase in staff almost doubled in 10 years. ICT industry currently occupies an important place in the structure of the Slovak economy, representing 4,2% of GDP, and at the same time has a noticeable influence on other related industries. This industry is very attractive for investors due to the presence of significant potential for growth due to a number of advantages in comparison with other branches of economy in Slovakia: High level of adaptation of ICT to the activity of enterprises; high value added and wages (1,2 – 4,0 ths. eur.); well-developed ICT related educational system; well-developed ICT institutional network; diversification of telecommunication segment; strategic geographical location from the perspective of time zonation; high quality data and network coverage; attractive investment incentives for the ICT sector (SARIO, 2021). In addition, ICT sector is actively supported by Slovak government, as a result, investors are offered attractive investment incentives for the ICT sector (tax reliefs; cash grants; contributions for the newly created jobs; rent/sale of real estate for a discounted price) and special R&D tax regime (200% of the R&D expenses can be deducted from the tax base) (SARIO, 2021). Thus, impact research of intangible assets impact on financial performance of Slovak ICT companies in modern conditions, there is a particularly urgent need to define the directions of development and ways of adjustment of their intangible investment policy.

Based on the important role of intangible assets in ensuring the efficiency of high-tech companies research hypothesis was formulated. The hypothesis of the study is the existence of a significant positive impact of intangible assets on the financial performance of ICT companies. Because the force of such influence may also depend from company size, level of borrowed capital and belonging to sub-sector of ICT industry, these factors should also be taken into account in the analysis impact of intangible assets on the financial performance, and the results obtained should be used in formulating recommendations to management of Slovak ICT companies for investments in in-

tangible assets.

2 THEORETICAL BACKGROUND

Problems of influence of intangible assets in their broad (economic) understanding on financial performance of high-tech companies are paid considerable attention of academicians. First of all, this is conditioned by the decisive role of intellectual capital for such enterprises in the context of the development of knowledge economy, which is based on ideas, R&D, innovations and technological progress. Scientists analyze of the impact of different intangible values on financial performance: intangible assets (the concept of IAS 38 (Deloitte Touche Tohmatsu Limited, 2022)), intellectual capital (as a combination of human, organizational, and client capital), or separate components of two data. These studies cover different types of enterprises from different countries of the world, which represent different sectors of the economy. Since intellectual capital includes, to the most extent, all intangible assets that are the result of human intellectual activity, this article also analyzes the impact of intellectual capital and its components on the financial performance of ICT companies. In addition, a number of researchers are conducting studies of the impact of intangible assets both on individual components of financial performance, in particular, on profitability, and on broader categories, in particular, on total performance of the company or companies value.

Table 1 lists the number of articles and their quotations, which reveal the relationship between "Intangible assets" / "Intellectual capital" and "Financial performance" in science-based databases of Scopus, Web of Science and Google Scholar.

The results of analysis of scientific databases are obtained (table 1) testify to the existence of a considerable number of publications in this direction of researches, as well as their influence on scientific works of other authors, which is confirmed by a considerable number of references to data of other authors and their constant growth from year to year. The cluster analysis of the key words of the articles from the databases of the Scopus and Web of Science on the basis of the use of VOSviewer allowed to confirm this conclusion. There was also a large number of publications that examined the impact of structural elements of intangible assets or intellectual capital (research and development, intangible resources, customer capital, structural capital, human capital, social capital, relational capital) on financial performance (figure 1). In addition, publications have been identified that investigate the impact of intangible assets or intellectual capital on other types of indicators that characterize the performance of the enterprise – firm performance, business performance, corporate performance, firm value, effectiveness, efficiency, profitability, ROA, competitive advantage etc. (figure 2).

Little attention is paid directly to the issue of impact of intangible values on financial performance of ICT companies, although the presence of significant positive relationships between with two variables is confirmed in the vast majority of results. Gan and Saleh (Gan and Saleh, 2008) the connection between intellectual capital components was studied corporate performance of high-techn companies listed on Bursa Malaysia, in particular, profitability, and productivity. Based on the use of regression analysis, it was found that companies with larger intellectual capital as a rule have better profitability (ROA) and more efficient productivity (ATO).

Li and Wang (Li and Wang, 2014) investigated the impact of different intangible assets (R&D expenditure, employee benefit, sales training) on profitability indicators (ROA) of Hong Kong Listed IT companies using regression analysis. They found a positive relationship between intangible assets and ROA.

Dženopoljac et al. (Dženopoljac et al., 2016) examined the role of intellectual capital and its key components in provision for financial performance (ROA, ROE, ROIC, ATO) of Serbian ICT sector companies during 2009–2013. They used Value-added intellectual coefficient (VAIC) as a measure of the IC contribution to value creation. The results obtained by the authors revealed that only one component of VAIC – CEE (capital-employed efficiency) had a significant impact on financial performance indicators, except for the indicator ROIC. Khan (Khan, 2018) also used VAIC as firms intangibility measure when analyzed the impact of intellectual capital on the financial performance of the 51 Indian IT companies for the period 2006–2016. He found a significant positive association of VAIC with profitability, and an insignificant relationship with productivity, and significant positive association of CEE with profitability and productivity of Indian IT companies.

Zhang (Zhang, 2017) analysed the relationship between degree of intangible assets and profitability for 17 Chinese listed telecommunication firms' for the period from 2014 to 2016. He found a positive and significant effect of Intangible assets ratio on ROA. Also, he emphasized the possibility of the inaccuracy of the obtained results due to the conservative nature of Chinese accounting standards rules in measuring intangible assets.

Huňady et al. (Huňady et al., 2019) examined the role of innovations in performance of ICT sector com-

Table 1: Number of scientific articles by direction of researches and their quotations in academic literature for the period 2018–2022 as of July 01, 2022 (via Scopus, Web of Science and Google Scholar databases).

	Results found			Sum of the times cited		
Searching phrases	Scopus	Web of Science	Google Scholar	Scopus	Web of Science	Google Scholar
"Intangible assets" and "Financial performance"	161	576	21	894	16100	38
"Intellectual capital" and "Financial performance"	329	970	494	2530	13904	2235

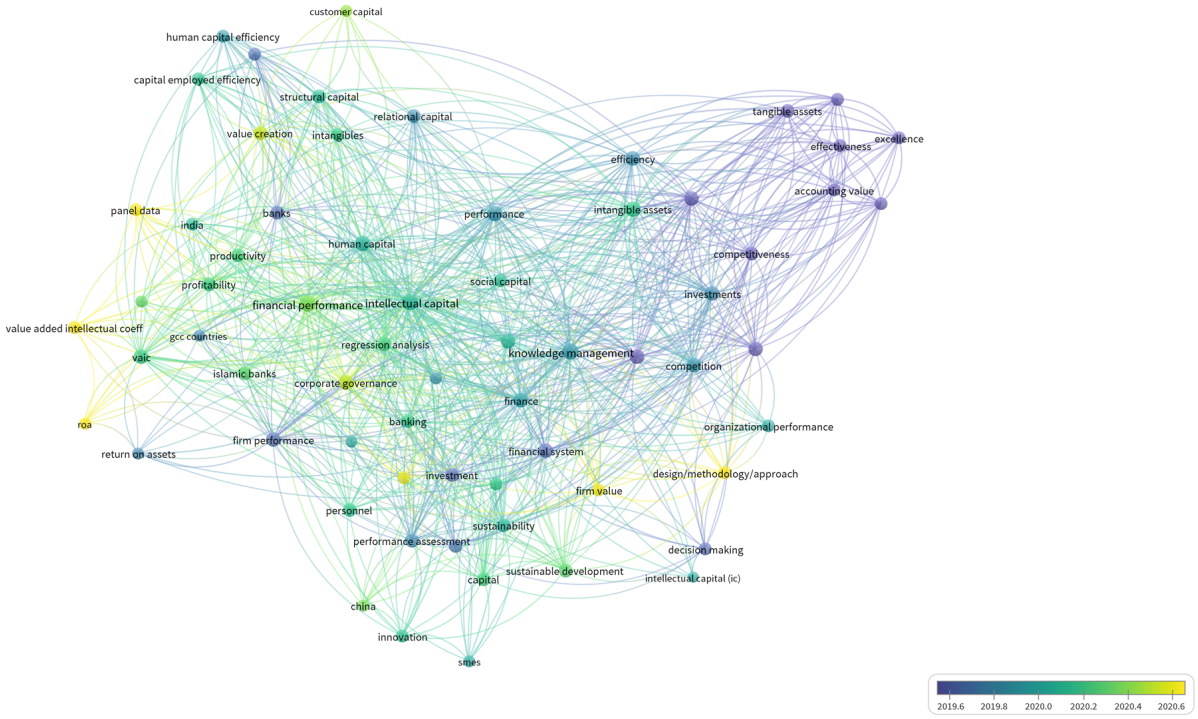

Figure 1: Bibliometric map of publications' keywords on the query "Intangible assets", "Intellectual capital" and "Financial performance" according to Scopus database in 2018–2022.

panies from 24 countries during the years 2008–2016. Using regression analysis for macro-level data, they found positive effect of R&D expenditure on apparent labour productivity and value added in ICT sector.

Qureshi and Siddiqui (Qureshi and Siddiqui, 2020) analyzed an effect of intangible assets on financial performance (ROA, ROE, ROIC, ATO and NPM) of the 80 global technology firms for the period from 2015 to 2018. They confirmed a significant negative effect of intangible assets on ROE, ROIC, ATO, and insignificant positive impact on companies' profitability. Moreover, the force of this influence considerably varies depending on the country's innovative development.

Lopes and Ferreira (Lopes and Ferreira, 2021) also investigated the impact of intangibles on the performance indicators of major world technological firms (Turnover, ROA, ROE, ROS, EPS), have received evidence of existence of negative correlation between all intangible variables, control variables (Size, Leverage) with ROA. These conclusions are also confirmed in labor Sundaresan et al. (Sundaresan et al., 2021), which investigated the impact of intangible assets on financial performance of 38 Taiwanese listed technology firms for the period 2015–2019. The authors also revealed the existence of a lack of a significant relationship between intangible assets and ROA, but found significant influence of size on ROA. At the same time, they confirmed significant impact of intangibles on ROE. Received Lopes and Ferreira (Lopes and Ferreira, 2021), Sundaresan et al. (Sundaresan et al., 2021) the results of the ROA are in direct contradiction with most of the conclusions obtained by the authors who studied impact of

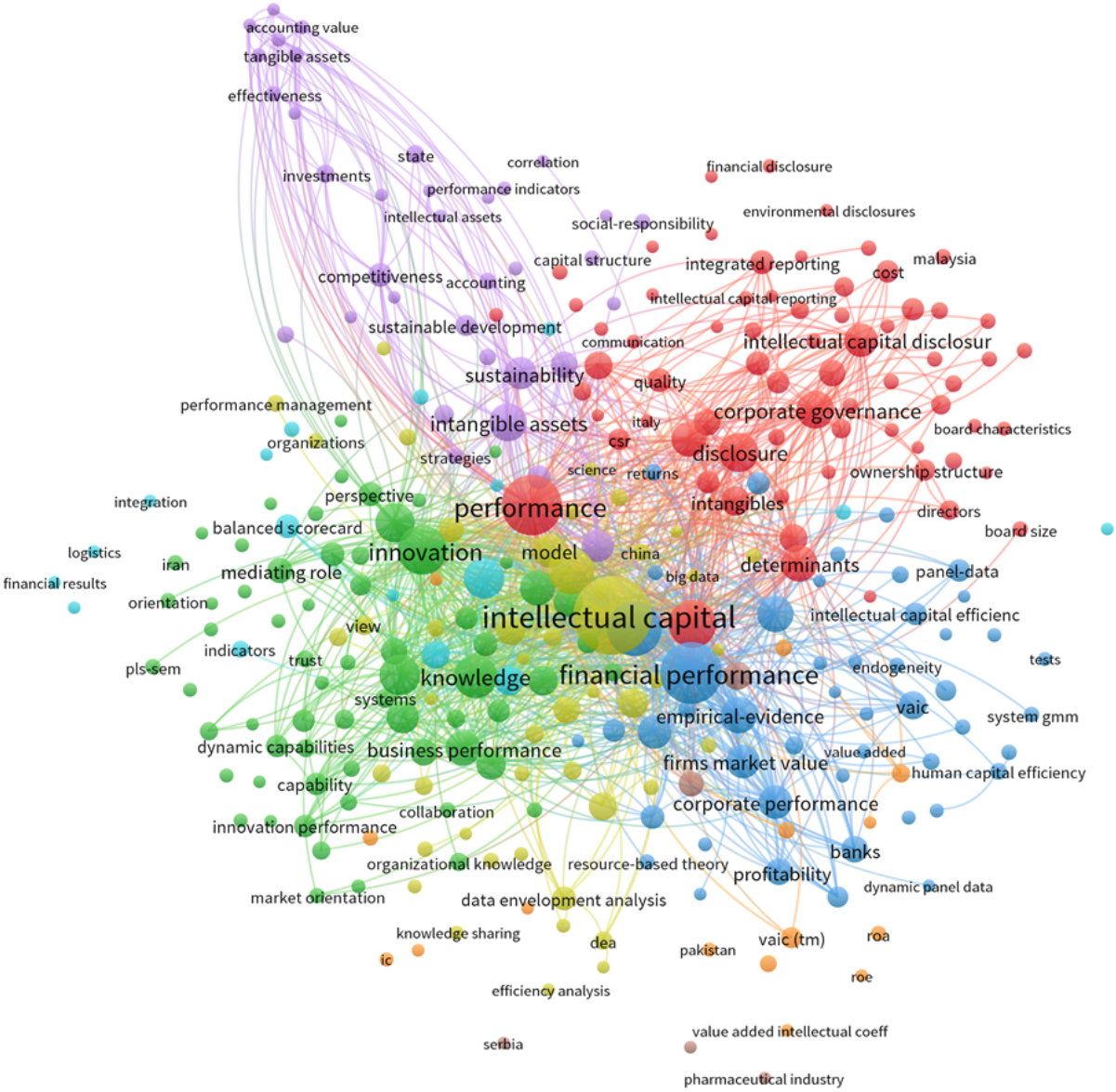

Figure 2: Bibliometric map of publications' keywords on the query "Intellectual capital" and "Financial performance" according to Web of Science database in 2018–2022.

intangibles on performance of ICT companies.

Radonić et al. (Radonić et al., 2021) studied the role of intellectual capital components (human, relational, structural and innovation capital) in ensuring the achievement of financial performance indicators (ROA, ROE, Net Profit, etc.) of South-East Europe IT industry companies. In their study, as a theoretical background they used a resource-based view on intellectual capital, which involves analyzing the impact of its individual components on financial performance indicators. In particular, the authors established that innovation capital has the strongest impact and human capital has an indirect impact on the financial performance of IT companies. A similar resource-based approach was also used by Serpeninova et al. (Serpeninova et al., 2022), who as a result of a study of the impact of intellectual capital on the profitability of Slovak software development companies (ROA, NPM, GPM, EBITM) found an absence of a significant relationship between them. The authors considered the main reason for this to be the imperfection of the current accounting standards, for instance, IAS 38, in terms of criteria for recognizing and evaluating the intellectual capital of enterprises.

The analysis of studies on the issues of the research made it possible to establish the existence of

mutually contradictory evidence regarding the impact of intangible assets on the financial performance. In general, this does not allow the management of enterprises to effectively control intangible values aimed at creating internal value, and for investors – to receive clear signals for making effective investments. Considering the above, the following objectives were formulated: to measure the relationship between intangible assets and the financial performance of Slovak ICT companies; to investigate which components of intangible assets have the most significant or insignificant impact on the financial performance of Slovak ICT companies; to form recommendations for improving the investment policy of ICT companies, based on the level of significance of the elements of intangible assets from the point of view of increasing financial results.

3 DATA AND METHODOLOGY

Sample selection. To determine whether intangible assets stimulate financial performance, was analyzed sample of 180 Slovak ICT companies for the period 2015–2019. In particular, the panel data information from financial statements of such enterprises, available in the open access, as well as the information from database "FinStat" was used to form panel data. Only those companies, for which the necessary information for the 5-year period was available, were included in the sample. The selected 180 companies provide a valid and complete set of data in order to carry out relevant statistical analysis.

Investigated enterprises proceeding from EU Economic Activity Classification and from the SK NACE 2 classification belongs to group 26 "Manufacture of computer, electronic and optical products", includes direct production of computers, computer peripheral equipment (input device, output device, input/output device), communication equipment (public switching equipment, transmission equipment, customer premises equipment), measuring, medical, navigation, radio, optical and other electronic equipment, as well as production of various types of accessories for such products (electrical boards, magnetic and optical media, etc.). In order to take into account the influence sub-sectors affiliation on financial performance of ICT companies two groups were allocated in their composition. The first group included enterprises dealing with the production of different types of electronics and components, and the second group involved enterprises producing communication equipment and components.

Based on the form of ownership, most of the companies investigated – 160, companies with limited liability, 16 – is a joint-stock company, 2 – production cooperative, 1 – limited partnership, 1 – general partnership. By type of ownership, the companies investigated are divided as follows: private domestic – 64%; foreign – 21%; international with a predominant private sector – 13%; cooperative – 1%; state – 1%.

Variables. In the research for characteristics of financial performance of ICT companies were used four dependent variables – Return on Assets, Net Profit Margin, Return on Equity, Assets Turnover, and used in their work by researchers for simiral empirical analysis of the relationship between intangibles values and company financial performance (Gan and Saleh, 2008; Dženopoljac et al., 2016; Qureshi and Siddiqui, 2020; Sundaresan et al., 2021; Radonić et al., 2021; Serpeninova et al., 2022). For explanation of a relation between intangible assets and financial performance of ICT companies used intangible assets variables – Research and Development Intensity, Research and Development Intensity Squared, Software, Intellectual Property Rights, Acquired Intangible Assets. The election of such independent variable is justified by the financial statements of Slovak ICT companies in the disclosure of information about intangible assets. As it was revealed Huňady et al. (Huňady et al., 2019), the firm's ICT sector account for significant share of total business R&D expenditure in economy in most countries. Therefore, in the analysis impact of intangible assets on financial performance of ICT sector an important role should be assigned to R&D indicators. As a result, the study does not use the indicator of R&D costs but uses two calculation ratios that characterize the R&D of the companies. In addition, based on previous studies (Ievdokymov et al., 2020; Zavalii et al., 2022; Serpeninova et al., 2022) in our study used three control variables – Leverage, Size and Dummy variable for ICT sub-sectors. Use of these variables will allow to control for a significant effects of company size, level of borrowing capital, and unseen role of ICT sub-sectors affiliation.

Types, calculation procedures, and abbreviations used in the Variables study are shown in table 2.

The dynamics of four indicators, that characterize financial performance of Slovak ICT companies (ROA, NPM, ROE, ATO) for the period 2015–2019 showed in figure 3.

Figure 1 displays the change in time of financial performance indicators for the 2015–2019 period. It allows to identify a number of common trends: Simultaneous growth in all indicators for 2017–2018 years; decrease in ATO, ROA and NPM indicators for 2015–2016 years, their growth in 2016–2018 years,

Table 2: Variable definitions and abbreviations.

Variable	Calculation (Source)	Abbreviation
Dependent Variables		
Return on Assets	Net turnover / Total Assets	ROA
Net Profit Margin	Net profit / Total Sales	NPM
Assets Turnover	Total Sales / Total Assets	ATO
Return on Equity	Net profit / Total Equity	ROE
Independent Variables		
Intangible Assets Variables		
Research and Development Intensity	Capitalized R&D Costs / Total Sales	RDI
Research and Development Intensity Squared	Squared function of RDI	RDI2
Software	Software (Intangible Asset)	SOFT
Intellectual Property Rights	Valuable Intellectual Property Rights	IPR
Acquired Intangible Assets	Acquired long-term intangible assets are charged until the time of their use	AIA
Control Variables		
Leverage	Total liabilities / Total Assets	LEV
Size	Logarithm of Total Assets	l_SIZE
Dummy variable for ICT sub-sectors	1 for electronic producers, 0 for communication producers	DVICTSS

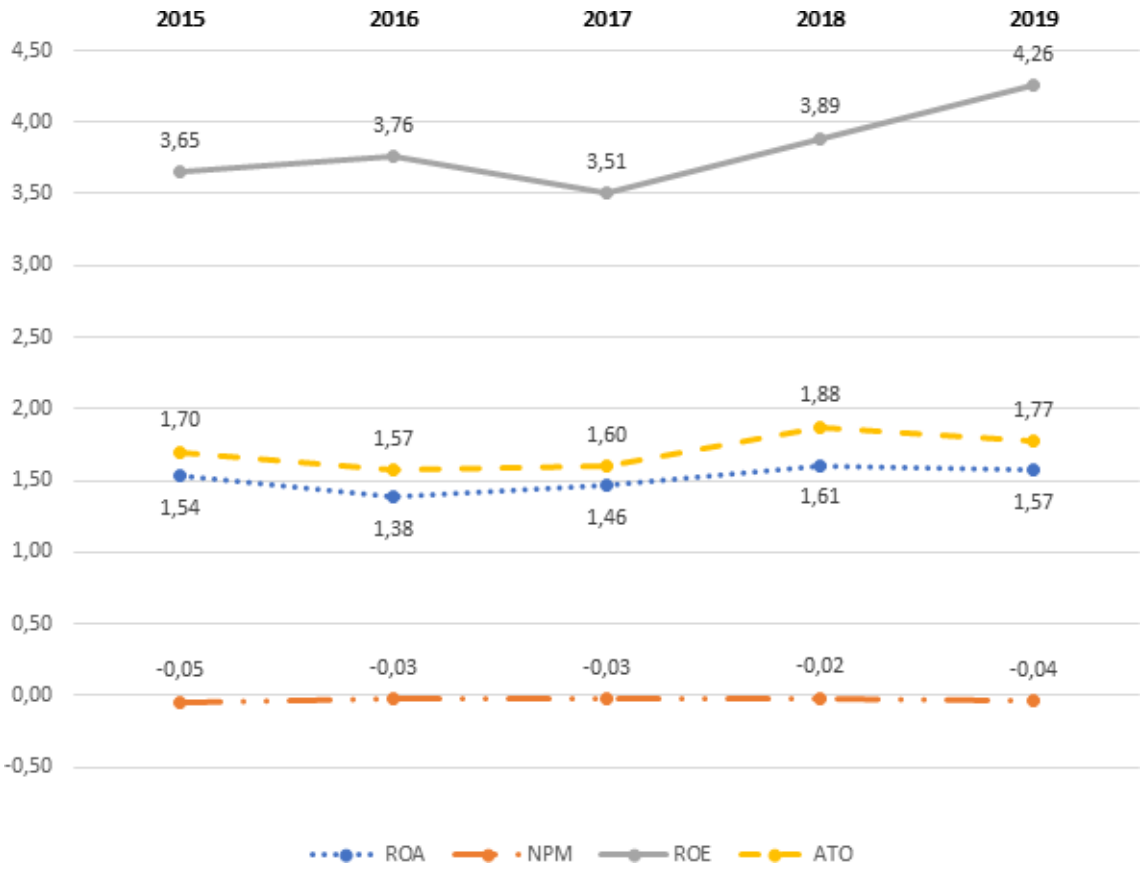

Figure 3: Dynamics of financial performance indicators of Slovak ICT companies for the 2015-2019 period.

as well as their simultaneous decrease in 2018–2019; during 2018–2019 years only growth of ROE indicator occurs. In general, common behavior was found for ATO, ROA and NPM, as well as almost completely different behavior of ROE compared to these indicators.

4 RESEARCH MODELS

To understand the relationship between intangible assets and financial performance indicators, this study examined four following models:

Model 1: $ROA_{it} = \alpha + \beta_1 \cdot RDI_{it} + \beta_2 \cdot RDI2_{it} + \beta_3 \cdot SOFT_{it} + \beta_4 \cdot IPR_{it} + \beta_5 \cdot AIA_{it} + \beta_6 \cdot LEV_{it} + \beta_7 \cdot l\_SIZE_{it} + \beta_8 \cdot DVICTSS_{it} + \varepsilon_{it}$

Model 2: $NPM_{it} = \alpha + \beta_1 \cdot RDI_{it} + \beta_2 \cdot RDI2_{it} + \beta_3 \cdot SOFT_{it} + \beta_4 \cdot IPR_{it} + \beta_5 \cdot AIA_{it} + \beta_6 \cdot LEV_{it} + \beta_7 \cdot l\_SIZE_{it} + \beta_8 \cdot DVICTSS_{it} + \varepsilon_{it}$

Model 3: $ATO_{it} = \alpha + \beta_1 \cdot RDI_{it} + \beta_2 \cdot RDI2_{it} + \beta_3 \cdot SOFT_{it} + \beta_4 \cdot IPR_{it} + \beta_5 \cdot AIA_{it} + \beta_6 \cdot LEV_{it} + \beta_7 \cdot l\_SIZE_{it} + \beta_8 \cdot DVICTSS_{it} + \varepsilon_{it}$

Model 4: $ROE_{it} = \alpha + \beta_1 \cdot RDI_{it} + \beta_2 \cdot RDI2_{it} + \beta_3 \cdot SOFT_{it} + \beta_4 \cdot IPR_{it} + \beta_5 \cdot AIA_{it} + \beta_6 \cdot LEV_{it} + \beta_7 \cdot l\_SIZE_{it} + \beta_8 \cdot DVICTSS_{it} + \varepsilon_{it}$

where: ROA, NPM, ATO, ROE – dependent variables, where *i* is entity and *t* is time;

α – Identifier;

μ – Variance introduced by the unit-specific effect for unit *i*;

β – Regression coefficient;

RDI, RDI2, SOFT, IPR, AIA – independent intangible variables, LEV, l_SIZE, DVICTSS – independent control variables;

ε_{it} – error term.

Figure 4 shows the conceptual framework of the study.

5 RESULTS

5.1 Descriptive Statistics and Correlations

The descriptive statistics (observation, mean, median, standard deviation, minimum, maximum) of a full sample are presented in table 3.

From table 3 it can be observed that the full sample is measured with 180 units. The largest deviations in variables are related to SOFT ($5{,}95 \cdot 10^4$), IPR ($2{,}89 \cdot 10^4$), AIA ($1{,}61 \cdot 10^5$) and ROE (4,30). Large differences between the minimum and the maximum values of ROA, ATO, and ROE show that the financial performance levels of ICT companies are quite distinct. For some variables (ATO, LEV, IPR, AIA, l_SIZE) the mean value is greater than the standard deviation value, as a result, the data in these variables have a small distribution. ROA, NPM, and ROE have a higher standard deviation than their mean. This indicates a relatively large set of ratios that will characterize the normal distribution curve and will not be outliers. The closeness of the mean (13,5) and median (13,3) values for l_SIZE indicates a high level of symmetry in the distribution of range values, that is, the size of the studied enterprises. The mean value of the LEV ratio is 0,438, and this means that approximately 44% of the total assets of ICT companies are financed through borrowed resources.

In general, correlation matrix of variables used in Models 1-4 (figure 5), testifies to absence multicollinearity problem, since in most cases, the correlation coefficient is less than 0,5 (–0,5). The only exception is the high correlation coefficient between variables RDI and RDI2 (0,9), which is understandable given that RDI2 is a squared function of RDI. However, as Özkan (Özkan, 2022) notes, the practice of applying such mutually-correcting indicators is normal in the regression analysis performed to check the effect of interrelated variables on financial performance indicators. In particular, simultaneous use in regression models of variables RDI and RDI2 allows to detect presence U-inverted relation between R&D and financial performance of a company.

5.2 Selection of Estimate Panel Data Parameter

The choice of estimate panel data parameter for each of the selected models plays an important role in the regression analysis of panel data. This parameter should be adequately correlated with the data used in the corresponding model. Proceeding from F-statistics test for Model 1 F(179; 712) = 1,17767 with p-value 0,0766456, which is more than 0,05 and confirms null hypothesis in relation to pooled OLS model. The need for such a choice estimate parameter for Model 1 also confirmed the application Breusch-Pagan test, according to which chi-square (1) $>$ 2,04561 p-value = 0,152645, which is larger than 0.05 and confirms zero hypotheses. The use of F-statistics test and Breusch-Pagan test also confirmed the need for use pooled OLS model as a quality estimate parameter for Model 2. For Model 3 after application F-statistics test it was received F(179; 712) = 1,23387 with p-value 0,0331413, that is less than 0,05 and testifies to the adequacy of application Fixed effects method (FEM). However, this conclusion is refuted as a result Breusch-Pagan test, according to chi-square (1) $>$ 3,58479 p-value = 0,0583107, which is larger than 0,05 and confirms zero hypothesis of adequacy pooled OLS model. Considering the results Hausman test (p-value = prob(chi-square (8) $>$ 4,34179) = 0,825045), according to which more appropriate is the application of Random effects method (REM) than FEM, for Model 3 more appropriate also

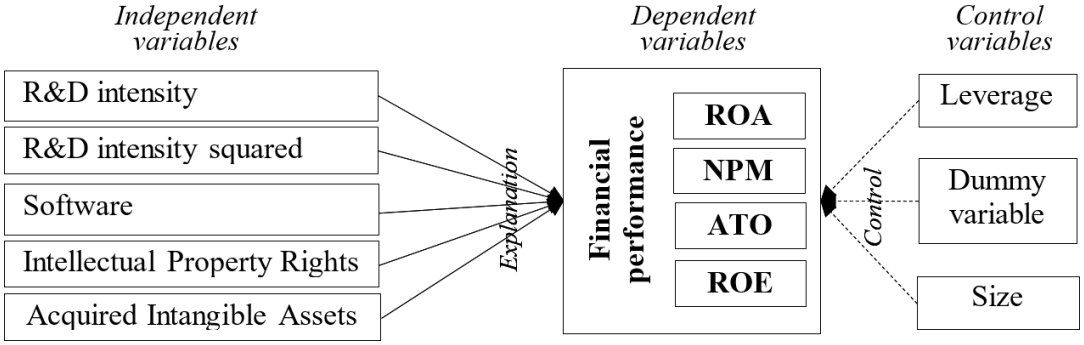

Figure 4: Conceptual framework of the study.

Table 3: Descriptive statistics of variables (based on observations 1:1 – 180:5).

Variables	Observation	Mean	Median	St. Dev.	Minimum	Maximum
ROA	180	1,51	1,27	1,52	2,75e-005	24,9
NPM	180	-0,0325	0,00798	0,501	-6,80	2,97
ATO	180	1,70	1,39	1,61	6,88e-005	24,6
ROE	180	3,81	2,33	4,30	0,000120	38,2
LEV	180	0,438	0,429	0,265	0,000	0,988
RDI	180	0,129	0,000	0,652	-0,0346	9,91
RDI2	180	0,442	0,000	4,96	0,000	98,2
SOFT	180	2,00e+004	0,000	5,95e+004	0,000	5,18e+005
IPR	180	8,27e+003	0,000	2,89e+004	-2,57e+004	2,67e+005
AIA	180	2,00e+004	0,000	1,61e+005	0,000	3,20e+006
l_SIZE	180	13,5	13,3	2,00	8,35	18,9

consider the application of pooled OLS model. For Model 4 after application of F-statistics test F(179; 712) = 1,32394 of p-value 0,00693691, which is less than 0,05 and shows the adequacy of application of FEM. This is the test followed by the p-value = P(chi-square (1) $>$ 6,04321) = 0,0139599.

5.3 Assumption Test Results

To verify the adequacy of the Panel data for Models 1-4 that is collected about ICT companies, it should be diagnosed using Normality test, Autocorrelation test and Heteroscedasticity test. Normality test for all Models 1-4 allowed to detect abnormal distribution of the error. For example, for Model 1 for chi-square (2) = 4119,75 p-value = 0, which is less than 0,05, and does not confirm zero hypotheses about the normal distribution of balances. Review null hypothesis about no first-order autocorrelation based on usage Wooldridge test for autocorrelation allowed to confirm it for all four models. In particular, for all Models 1-4 p-value it is more than 0,05 (0,73367; 0,923389; 0,193049; 0,227822), confirming null hypothesis. White test was used to check the heteroscedasticity of a models 1–3. Since the obtained p-value for each of the three models (0,284134; 0,999935; 0,421088) is more than the critical value, the zero hypothesis about the absence of heteroscedasticity is forgiven. For Model 4 with estimate parameter FEM was applied non-parametric Walk test, which also was established the presence of heteroscedasticity. In particular, chi-square(180) = 78593,1 p-value = 0 was received. Since p-value is less than 0,05, there is an inhomogeneous observation and a different variance of a Model 4 random error, which confirms the existence of heteroscodesticity.

To solve the problem of inadequacy of all Models 1–4 used by this data due to the problem of improper distribution of the error and heteroscedasticity, the use of robust estimators is proposed. They help minimize or eliminate impact of outliers in a Models 1-4, improving the results of panel data regression analysis. Practice of use robust standard errors in regression analysis was also used in research of scientists who study the impact of intangible assets and their components on the performance of enterprises (Özkan, 2022; Serpeninova et al., 2022).

5.4 Panel Data Regression Results

Model 1 (ROA). Tables 4–5 show the results of regression analysis performed using pooled OLS model. They show how the independent variable will affect the dependent variable, which of the regres-

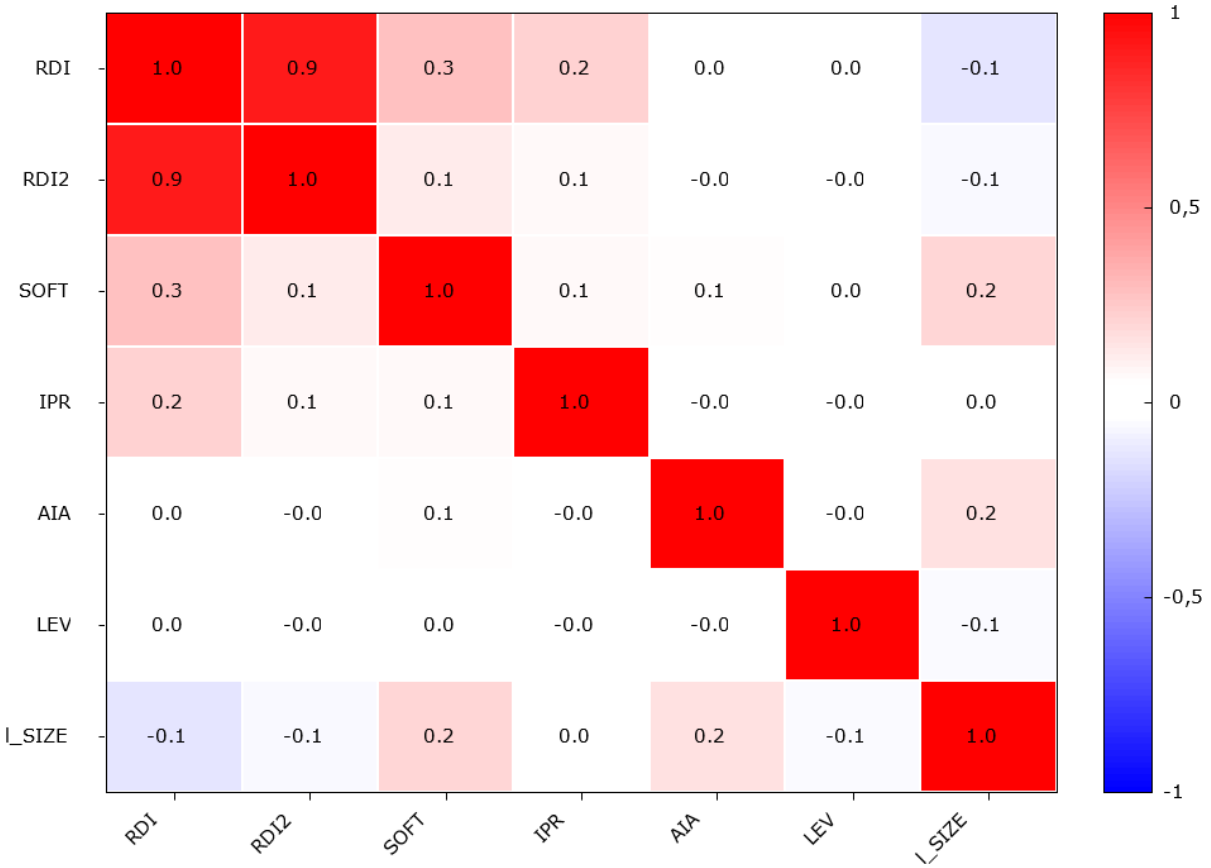

Figure 5: Correlation matrix of variables used in Models 1-4 (calculated via GRETL software package).

sions have significant influence, force and direction of such influence.

Model 1 can be interpreted through the following equation:

$\hat{y} = 1,83324 - 1,16410 \cdot 10^{-6}x_1 + 0,110937x_2 + 1,65440 \cdot 10^{-6}x_3 + 1,34184 \cdot 10^{-6}x_4 - 4,98766 \cdot 10^{-7}x_5 - 0,137738x_6 - 0,0379800x_7 + 0,168307x_8$
where: $\hat{y}$ – ROA; x_1 – RDI; x_5 – AIA; x_2 – RDI2; x_6 – LEV; x_3 – SOFT; x_7 – l_SIZE; x_4 – IPR; x_8 – DVICTSS.

Based on the results of the regression analysis, const, RDI, RDI2, SOFT and AIA are statistically significant (there are stars in the last column of table 4), having the highest level of significance at the 1% level. Accordingly, these indicators have the highest impact on ROA. In addition to RDI and AIA, other significant indicators have a direct impact on ROA and RDI and AIA are rotating. The presence of a different direction of influence in RDI and RDI2 indicates the presence of U-inverted relationship between R&D and ROA (Lehenchuk et al., 2022). Similar U-inverted behavior is common to most of the costs of non-material nature, in particular, social and environmental costs (Sokil et al., 2020). The results also show that there is no significant influence of control variables (Lev, l_SIZE, DVICTSS) on ROA.

The overall content of the regression coefficient of Model 1 is that with an increase of 1 directly influencing the ROA, the last increase in the ratio will be increased. For example, if SOFT is increased by 1, the ROA will increase by 1,65440 $\cdot 10^{06}$. And for indicators that have a positive impact on ROA, their increase by 1 for ICT enterprises will result in corresponding decrease of ROA (depending on the coefficient of regression).

Table 5 indicates that the coefficient of determination (R-squared) of Model 1 is 0,047173. This means only that 4,7% of the variation of ROA can be explained by the variation of the independent variables (const, RDI, RDI2, SOFT, IPR, AIA, LEV, l_SIZE, DVICTSS).

Model 2 (NPM). Model 2 can be interpreted through the following equation:

$\hat{y} = -0,274718 + 0,0626252x_1 - 0,00669466x_2 - 5,13111 \cdot 10^{-8}x_3 + 2,00654 \cdot 10^{-7}x_4 - 5,88982 \cdot 10^{-8}x_5 - 0,0630010x_6 + 0,0269143x_7 - 0,0517929x_8$
where: $\hat{y}$ – NPM; $x_1 - x_8$ – the same as in Model 1.

Table 4: Model 1 (ROA). Pooled OLS model (Robust standard errors), using the observations 1–900.

Variable	Coefficient	Standard error	z	P-value	Significance by t-statistics
const	1,83324	0,632512	2,898	0,0038	***
RDI	−1,16410	0,157720	−7,381	<0,0001	***
RDI2	0,110937	0,0175566	6,319	<0,0001	***
SOFT	$1{,}65440 \cdot 10^{-6}$	$5{,}38521 \cdot 10^{-7}$	3,072	0,0021	***
IPR	$1{,}34184 \cdot 10^{-6}$	$9{,}24827 \cdot 10^{-7}$	1,451	0,1468	
AIA	$-4{,}98766 \cdot 10^{-7}$	$1{,}38889 \cdot 10^{-6}$	−3,591	0,0003	***
LEV	−0,137738	0,214780	−0,6413	0,5213	
l_SIZE	−0,0379800	0,0454674	−0,8353	0,4035	
DVICTSS	0,168307	0,105500	1,595	0,1106	

Note: *** Significant at the 1% level.

Table 5: Model 1 (ROA). Pooled OLS model (Robust standard errors), using the observations 1–900.

Indicator	Value	Indicator	Value
Mean dependent var.	1,511304	S.D. dependent var.	1,524745
Sum squared resid.	1991,445	S.E. of regression	1,495014
R-squared	0,047173	Adjusted R-squared	0,038618
F(8, 179)	21,20706	P-value (F)	$1{,}86 \cdot 10^{-22}$

Table 6: Model 2 (NPM). Pooled OLS model (Robust standard errors), using the observations 1–900.

Variable	Coefficient	Standard error	z	P-value	Significance by t-statistics
const	–0,274718	0,116547	–2,357	0,0184	**
RDI	0,0626252	0,0295138	2,122	0,0338	**
RDI2	–0,00669466	0,00314309	–2,130	0,0332	**
SOFT	$-5{,}13111 \cdot 10^{-8}$	$1{,}17552 \cdot 10^{-7}$	–0,4365	0,6625	
IPR	$2{,}00654 \cdot 10^{-7}$	$1{,}99115 \cdot 10^{-7}$	1,008	0,3136	
AIA	$-5{,}88982 \cdot 10^{-8}$	$2{,}90523 \cdot 10^{-8}$	–2,027	0,0426	**
LEV	–0,0630010	0,0813673	–0,7743	0,4388	
l_SIZE	0,0269143	0,00838749	3,209	0,0013	***
DVICTSS	–0,0517929	0,0272405	–1,901	0,0573	*

Note: * Significant at the 10% level; ** Significant at the 5% level; *** Significant at the 1% level.

Table 7: Model 2 (NPM). Pooled OLS model (Robust standard errors), using the observations 1–900.

Indicator	Value	Indicator	Value
Mean dependent var.	-0,032511	S.D. dependent var.	0,501315
Sum squared resid.	222,9308	S.E. of regression	0,500203
R-squared	0,013291	Adjusted R-squared	0,004432
F(8, 179)	2,238141	P-value (F)	0,026686

Based on table 6, the most significant effect on NPM is changed to l_SIZE. Accordingly, with the growth of the enterprise volume by 1 increases the value of the NPM indicator by 0,0269143. Significant at the 5% level in NPM explanation have regressors const, RDI, RDI2 and AIA. Also significant at the 10% level is the DVICTSS regression, which has an indirect effect. Indirect effects on NPM are also affected by the RDI2 and AIA indicators. This means that, as investments in such types of intangible assets increase, the corresponding (depending on the regression coefficient) reduction of the dependent variable will occur. By comparing the coefficient of Model 2 with RDI and RDI2, it is possible to note the existence of the upper limit of investments in R&D of Slovak ICT companies, after which their negative impact on NPM will already be observed.

Table 7 indicates that the R-squared of Model 2 is 0,01, a very low value and does not allow to speak about the significant role of intangible assets in NPM provision. This means that 1,33% of the variation of the NPM can be explained by the variation of regressors.

Model 3 (ATO). Model 3 can be interpreted

Table 8: Model 3 (ATO). Pooled OLS model (Robust standard errors), using the observations 1–900.

Variable	Coefficient	Standard error	z	P-value	Significance by t-statistics
const	2,80330	0,637648	4,396	<0,0001	***
RDI	–1,42622	0,174982	–8,151	<0,0001	***
RDI2	0,134772	0,0192228	7,011	<0,0001	***
SOFT	$2{,}76920 \cdot 10^{-6}$	$6{,}38619 \cdot 10^{-7}$	4,336	<0,0001	***
IPR	$4{,}61116 \cdot 10^{-6}$	$1{,}59970 \cdot 10^{-6}$	2,883	0,0039	***
AIA	$-4{,}38715 \cdot 10^{-7}$	$1{,}36505 \cdot 10^{-7}$	–3,214	0,0013	***
LEV	–0,139781	0,233510	–0,5986	0,5494	
l_SIZE	–0,0951285	0,0438796	–2,168	0,0302	**
DVICTSS	0,150857	0,124085	1,216	0,2241	

Note: ** Significant at the 5% level; *** Significant at the 1% level.

Table 9: Model 3 (ATO). Pooled OLS model (Robust standard errors), using the observations 1–900.

Indicator	Value	Indicator	Value
Mean dependent var.	1,703817	S.D. dependent var.	1,614880
Sum squared resid.	2212,759	S.E. of regression	1,575898
R-squared	0,056170	Adjusted R-squared	0,047696
F(8, 179)	15,95424	P-value (F)	$1{,}15 \cdot 10^{-17}$

through the following equation:

$\hat{y} = 2{,}80330 - 1{,}42622x_1 - 0{,}134772x_2 + 2{,}76920 \cdot 10^{-6}x_3 + 4{,}61116 \cdot 10^{-6}x_4 - 4{,}38715 \cdot 10^{-7}x_5 - 0{,}139781x_6 - 0{,}0951285x_7 + 0{,}150857x_8$

where: $\hat{y}$ – ATO; $x_1 - x_8$ – the same as in Model 1.

For dependent variable ATO except for LEV and DVICTSS, all other regressions are significant. In particular, l_SIZE significant at the 5% level, and all other regressions (const, RDI, RDI2, SOFT, IPR and AIA) significant at the 1% level. Direct effects on ATO from the regression data are RDI2, SOFT and IPR, while others are affected. In particular, as in Model 1 for ROA, making a small amount of investments in R&D of Slovak ICT companies has a negative impact on ATO. Only their implementation from a certain volume, in particular, in the volume of RDI2, ensures the growth of ATO. Based on an equal to 1,3 RDI2 growth by 1 increases the NPM value by 0,0269143. Table 9 indicates that the R-squared of Model 3 is 0,056. This means that 5,61% of the variation of the ATO can be explained by the variation of regressors.

Model 4 (ROE). Model 4 can be interpreted through the following equation:

$\hat{y} = -1{,}06067 - 2{,}79903x_1 + 0{,}272431x_2 + 5{,}89712 \cdot 10^{-6}x_3 + 8{,}97938 \cdot 10^{-7}x_4 - 1{,}27997 \cdot 10^{-6}x_5 + 8{,}94081x_6 + 0{,}0265371x_7 + 0{,}392670x_8$

where: $\hat{y}$ – ROE; $x_1 - x_8$ – the same as in Model 1.

Model 4 has five statistically significant regressors – RDI, RDI2, SOFT, AIA and LEV (table 10). All of them have the highest level of significance – 1%, therefore they have the greatest influence on the dependent variable (ROE). The equation of Model 4 shows that most of the independent variables (RDI2, SOFT, IPR, LEV, l_SIZE and DVICTSS) have a direct influence, and only two variables (const, RDI and AIA) have a rotational influence on the ROE. As in Models 1 and 3, Model 4 has a U-inverted relationship between R&D and ROA, characterized by the need to increase investment in R&D of Slovakia ICT companies to ensure their positive impact on ROE.

Table 11 indicates that the LSDV R-squared of Model 4 is 0,51. This is quite a high value compared to the 1–3 models, but not enough to speak about the significant role of intangible assets in providing of financial performance of ICT companies. This means that 51,61% of the variation of the ROE can be explained by the variation of the regressors.

6 DISCUSSION

The results obtained in the article partially confirm the conclusions of the analyzed works on the role of intangible assets in the promotion of financial performance of high-tech companies. As for some regressions, they are in conflict with such conclusions. The existence of a positive and significant relationship between intangible assets and some financial performance measures was confirmed, which is also set in the works of Li and Wang (Li and Wang, 2014), Dženopoljac et al. (Dženopoljac et al., 2016), Zhang (Zhang, 2017). The presence was also established of negative and significant impact of AIA on all financial performance indicators, this confirms the results of the research (Qureshi and Siddiqui, 2020; Lopes

Table 10: Model 4 (ROE). FEM (Robust standard errors), using the observations 1–900.

Variable	Coefficient	Standard error	z	P-value	Significance by t-statistics
const	–1,06067	1,27812	–0,8299	0,4066	
RDI	–2,79903	0,466001	–6,006	<0,0001	***
RDI2	0,272431	0,0565526	4,817	<0,0001	***
SOFT	$5{,}89712 \cdot 10^{-6}$	$2{,}18175 \cdot 10^{-6}$	2,703	0,0069	***
IPR	$8{,}97938 \cdot 10^{-7}$	$3{,}30604 \cdot 10^{-6}$	0,2716	0,7859	
AIA	$-1{,}27997 \cdot 10^{-6}$	$3{,}62115 \cdot 10^{-7}$	–3,535	0,0004	***
LEV	8,94081	0,614350	14,55	<0,0001	***
l_SIZE	0,0265371	0,0848603	0,3127	0,7545	
DVICTSS	0,392670	0,344744	1,139	0,2547	

Note: *** Significant at the 1% level.

Table 11: Model 4 (ROE). FEM (Robust standard errors), using the observations 1–900.

Indicator	Value	Indicator	Value
Mean dependent var.	3,812005	S.D. dependent var.	4,304137
Sum squared resid.	8058,382	S.E. of regression	3,364216
LSDV R-squared	0,516144	Within R-squared	0,348421

and Ferreira, 2021). At the same time, the direction and influence of different types of regressions used in the study are not the same in all formed models, but depends on a particular kind of financial performance indicator. One of the reasons for this is that the relationship between intangible assets on financial performance may depend on macroeconomic factors, in particular, on the level of science capacity in the industry and on the level of innovation in the country, which is noted by Qureshi and Siddiqui (Qureshi and Siddiqui, 2020). Another reason for such results may be incomplete information about intangible assets disclosed in the financial statements of Slovak ICT companies. In turn, this is a consequence of the conservatism of the current methodology of recognizing and evaluating intangible assets, which Zhang (Zhang, 2017) also points out, Radonić et al. (Radonić et al., 2021). Therefore, the findings of this study confirm the proposal of Serpeninova et al. (Serpeninova et al., 2022) regarding the necessity of expanding the criteria for recognizing and the structure of financial reporting for high-tech companies regarding intangible assets.

The results of the survey refutes the conclusions of Gan and Saleh (Gan and Saleh, 2008) on the positive impact of the company's size on the improvement of financial performance (ROA), but such an impact was found with respect to NPM. The above confirms the hypothesis of Del Monte and Papagni (Del Monte and Papagni, 2003) that to increase the returns from intangible investments should be provided with their proper quality level, not quantitative imitations. Therefore, an intangible investment policy of ICT companies should be based not only on quantitative parameters, that is, not on the basis of total investment in the company, but on the individual role of certain types of intangible assets in improving of financial performance.

The study has some limitations, which should be taken into account by other scientists when evaluating the results of a study. Firstly, given the sufficient breadth of the term "financial performance", a list of dependent variables used in the study can be specified. Second, the list of independent variables used in a study can be expanded by uncapitalized intangible assets that also affect the financial performance of Slovakia ICT companies. However, it is necessary to separate from the composition of different types of expenses of ICT companies those expenses connected with creation of intangible assets (client, ecological, social, etc.), as such data are not in financial statements of companies. Third, to determine the role of intangible assets in improvement of financial performance, research can be carried out not only on the examples of companies of ICT industry, but also on the example of other branches of economy. This will allow to carry out an interindustry comparison and establish in which areas of management of enterprises should pay the most attention to development of an intangible investment policy.

7 CONCLUSION

The present research was performed in order to study the effects of intangible assets on the financial performance of high-tech companies. For this purpose, the activity of 180 Slovak ICT companies over the period 2015–2019 was analyzed. Such research is especially

relevant in the conditions of the ICT sector's important role in the development of the Slovak economy. As a result, Slovak Government creates the necessary favorable institutional conditions for further development of ICT companies and implements special programs to stimulate investment in this sector.

Panel data regression analysis was used as the basic method of research. Return on assets, Net Profit Margin, Assets Turnover and Return on Equity were selected as dependent variables that characterize financial performance. For each of these indicators a model was formed, which included eight independent variables. It is intangible assets variables (Research and Development Intensity, Research and Development Intensity Squared, Software, Intellectual Property Rights, Acquired Intangible Assets), and three – control variables (Leverage, Size, Dummy variable for ICT sub-sectors) for the 2015–2019 period. For each of the models the estimate panel data parameter was chosen based on F-statistics test, Breusch-Pagan test and Hausman test (Model 1–3 – pooled OLS model, Model 4 – FEM). The adequacy of each of the models of the formed data was tested on the basis of the Normality test, Autocorrelation test (Wooldridge test for autocorrelation) and Heteroscedasticity test (White test, Walk test) with the application of the GRETL software package. Based on the incomplete adequacy of the models to the generated data the expediency of robust standard errors use was substantiated.

The hypothesis of the study was partially confirmed as a result of the conducted research. The results of panel regression analysis have shown that not all types of intangible assets have a significant positive impact on the financial performance of Slovakia ICT companies. Only RDI, RDI2 and AIA have significant influence of different forces on all four types of dependent indicators, which characterize the financial performance of the company. This is evidence of the expediency of management making investments in these types of intangible assets of the Slovak ICT companies. The presence of different directions of influence of RDI and RDI2 on indicators of the financial performance testifies to existence of U-inverted relationship between R&D and such indicators of two types. By the first type (Models 1, 3, 4) RDI is out of the zone of return of investments in R&D, and RDI2 is within it. And by the second type (Model 2) RDI enters the profit zone, and RDI2 is already outside it. Based on these results, management of ICT companies may decide to make additional investments in R&D or to reduce them in order to provide better financial performance of the company. In all models studied, the independent variable AIA has a high level of significance, but turns to the performance of financial performance of Slovak ICT companies. This shows that long-term intangible assets have not yet been put into operation, and therefore need to be more quickly brought into business processes of Slovak ICT companies. In addition, there should be an effective system of planning processes for acquisition of intangible assets in accordance with the company's needs as an element of its intangible investment policy.

Research results also show that when using leverage, Size and Dummy variable for ICT sub-sectors as a control variables only l_SIZE has a significant impact on NPM (1% level) and ATO (5% level), DVICTSS on NPM (10% level) and LEV on ROE (1% level). That is, the level of influence of control variables on the indicators of financial performance is partial and varied, and applies only to certain types of them, in particular, not at all affecting ROA.

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The Institutional and Legal Provision of Human Social Security Under the War

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Keywords: Human Social Security, War, Institutional Provision of Human Social Security, Legal Provision of Human Social Security, State Policy, Human Social Security Risks and Threats.

Abstract: Theoretical approaches to the essence of human social security and the study of ideas about social security among residents of the southern and eastern regions of Ukraine are considered. It made it possible to formulate the essence of human social security under the war conditions. The institutional provision of human social security and its components were studied: in the field of economic relations, in the field of institutionalization of employment relations, in the field of the organizational mechanism for regulating the labor market, in the field of migration. An analysis of foreign experience in ensuring human social security made it possible to single out American, European and Ukrainian models. Since Ukraine has chosen the European integration course, it is advisable to consider the European model of social security and the possibilities of its application in Ukraine. At the same time, the American model has its own characteristics that may be useful for Ukraine. The recommendations for improving the institutional and legal provision of human social security under the war include the following: at the state level, it is necessary to ensure the integration of the social component in the strategy for implementing socio-economic reforms; anticipate the norms of public democratic control in legislative and regulatory documents; a modern system of public administration to ensure the social security of Ukraine can be based on how to maintain the development of the economy, take in accordance with specific principles for the implementation of the national social system.

1 INTRODUCTION

In the context of a complex and unpredictable military-political situation in Ukraine, caused by a deep full-scale Russian military invasion of Ukraine, the problem of human social security deserves special attention, which directly affects the effectiveness of changes in all spheres of public life.

War is an extreme manifestation of social danger, which is an extreme form of aggravation of social relations – social, economic, political, religious, interstate. This is a very acute form of resolving conflicts between states, groups of people using modern means of destruction and accompanied by violence, large-scale destruction, death of people, components of nature, technology.

According to the UN High Commissioner for Human Rights, since the beginning of the large-scale invasion of Russian troops into Ukraine, more than 2,000 civilians have been killed, about 3,000 people have been injured, and more than 15,000 have gone missing since the start of Russia's war against Ukraine. Hundreds of cases of rape by Russian invaders in Ukraine have already been recorded, including underage girls, children and even a baby.

During two months of the war, about 5 million people left Ukraine – mostly women and children, and another 7 million Ukrainians became internally displaced persons. This necessitates further steps to find ways to improve the institutional and legal support of human social security.

Given the relevance of the study, the purpose of this paper is to analyze the institutional and legal provision of human social security under the war, re-

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search foreign experience and develop recommendations for its improvement in Ukraine. The object of the research is the institutional and legal provision for ensuring human social security; the subject is a set of theoretical and practical aspects of institutional and legal provision for ensuring human social security under the war. In recent years, a number of informative analytical studies have been published by domestic and foreign experts, which examine the goals, mechanisms, technologies and means of Russian aggression in Ukraine and Europe.

2 RESEARCH METHODS

Human social security is the foundation of the fundamental research methodology. Systematic approach was used in order to determine the mechanism, types and indicators of human social security (Halytsa and Hetman, 2017; Kharazishvili and Grishnova, 2018). Methods of theoretical generalisation were applied to study and systematise types of social security and public policy concepts for ensuring social security (Libanova and Paliy, 2004; Krokhtina, 2004).

Some authors used conceptual approaches to the essence of human social security (Nikolaev, 2011; Varnalii et al., 2022a). Groupings and tabular method were used to characterize types of institutional risks and treats in human social security (Iliash, 2011; Kharazishvili and Grishnova, 2018), study information and analytical systems of social protection of the population in different countries (Kharazishvili et al., 2020; Lebanidze, 2017; Yasutis, 2017), analyze state policy of ensuring human social security (nsa, 2018; Sydorchuk, 2019; Varnalii et al., 2022b). Scientific and methodical approach was used to develop strategic directions for improving human social security (Yasutis, 2017; nsa, 2018; Sydorchuk, 2019; Varnalii et al., 2022b).

Research data show that the problems of the institutional and legal provision of human social security under the war are not sufficiently studied.

To achieve the goal of this paper, we used general scientific and special methods, such as:

1) the structural-functional method (for disclosure the treats of human social security). Thus, we used this method for revealing the influence mechanism of treats on main indicators of human social security. First, we identified main groups of threats to human social security and their components, revealed their interconnection within one system. Having identified the treats of human social security, we defined the directions for developing recommendations to prevent treats and minimize related risks;
2) the comparison method (for comparing the legislation for ensuring human social security between Ukraine and other countries). In turn, it gives impetus to the formation of directions for ensuring human social security under the war.

3 THEORETICAL APPROACHES TO THE ESSENCE OF HUMAN SOCIAL SECURITY

The concept of “social security” in the scientific literature began to take shape in the late 90s of the last century. This category was declared in the Copenhagen Declaration on Social Development (United Nations, 1995), which touched upon the social aspects of sustainable development, designed to ensure social security in the world.

An important issue is the formation of appropriate conditions for the implementation of one of the fundamental human needs – the need for security. Back in 1994, a proposal appeared in the practice of the UN to consider such components of security as political, economic, personal, food, health, community and environmental security (UNDP (United Nations Development Programme), 1994). And if in the past it was believed that because of security at the state level, it is possible to ensure the security of an individual, today it works the other way around: the center of the new concept of security is not the state, but the person.

The term “social security” first found its concrete expression in an international document – the Copenhagen Declaration on Social Development adopted by the World Summit for Social Development in 1995.

In a democratic society, the interests of the social security of a person and the state should generally correlate and be harmoniously balanced. In the legal field of Ukraine there is no official definition of the category “social security”, and the term “social security” has recently entered the scientific and political circulation.

Consequently, the individual, not the state, is in the center of the new concept of security. An increasing number of factors testify that if we start with human security and build state policy and the work of non-governmental actors around this, then the life of society becomes more predictable and integrated. Moreover, society’s ability to resist both internal and external threats will gradually increase.

Human social security is the ability and readiness of the state, society and individual to protect them-

selves from dangers and threats to life, health, basic social values – human rights and freedoms.

In modern democracies, the concept of "human security" is gaining momentum. In fact, this is a kind of transition from a very narrow to a broad understanding of security. The absence of war or other threats to the life and health of citizens, the low level of crime does not mean a safe environment in the modern world. First, it is formed at different levels: from personal security, security of life in a particular community to the national and international level. Secondly, security is decomposed into various components, and only their totality determines how safe the citizen's environment is.

Libanova and Paliy (Libanova and Paliy, 2004), when revealing the essence of social security, also holds the opinion that the state of human security, is the result of the implementation of a social protection policy. At the same time, she describes social security as one of the components of state security, interpreting it as a state of protection from threats to social interests. According to Krokhtina (Krokhtina, 2004), social security is formed in the system of legal and social guarantees that allow a person to function most effectively within a certain socio-political formation.

In our opinion, human social security should be understood as the degree of protection of the vital socio-economic interests of a person, his rights, freedoms and values from internal and external, real and potential threats. It is associated with the observance of the most important social standards: overcoming poverty, the growth of human potential (life expectancy and level of education), increasing the purchasing power of the population, the quality of working life, the protection of the family, motherhood and childhood; health services; environmental standards, etc.

4 CURRENT SOCIO-ECONOMIC SITUATIONS OF THE POPULATION

According to the research of the sociological group "Rating" in the framework of the project "Ukraine in the conditions of war" (sur, 2022), among Ukrainians who worked before the war, half of them (53%) do not work today. 22% of them work as usual, 21% of them work remotely or partially, and only 2% of them have found a new job. This is an indicator of not only economic problems, but also social and psychological ones. Work is not only an economy, it is a habitual way of life, communication and interaction with others. A significant proportion of citizens have lost such support and are more likely to have received a higher level of maladaptation. Most of all, this affected residents of the east (74%), young people under 35 years old (60%) and those who left their city (66%).

- The economic situation as a result of the war did not change only for 18% of citizens, for 52% of them it deteriorated significantly, for 28% of them it rather deteriorated. Income "closes" the basic needs of a person, gives security and reduces anxiety in front of an uncertain future.
- 40% of respondents believe that their savings will be enough only for a month. However, the COVID-19 pandemic taught Ukrainians how to save money and the percentage of those who increased their material security during the crisis increased (during the first quarantine, 55% of them believed that they would only have enough savings for a month). Therefore, given the socio-economic and psychological importance of employment, it is now very important to resume work as much as possible.

Scientists from the Institute of Industrial Economics of NAS of Ukraine (nsa, 2018) have researched, that human social security is manifested mainly in favorable and safe living conditions (63,8%), while a healthy lifestyle occupies the lowest position at 1,9% (figure 1).

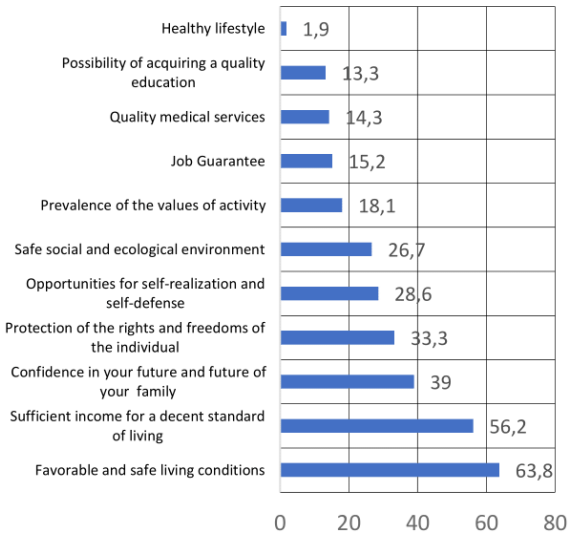

Figure 1: Assessment of external and internal factors of manifestation of human social security (% to the number of experts) (nsa, 2018; Sydorchuk, 2019).

It is important to note that even in the conditions of war, security in the minds of people does not focus solely on ending the war or establishing law and order, but covers various areas of their lives. Thus,

in 2020, Heinrich Böll Foundation conducted a study of security perceptions among residents of four southern and eastern regions of Ukraine. The key task of the researchers was to find out: what do the citizens themselves in the front-line areas think about security, what does it mean for them, and, most importantly, what does it consist of?

It could be assumed that this part of the population, like no other, would be inclined to a narrow view of security, since along with war, the local population directly or indirectly suffers from the consequences of the conflict. However, the study showed very different results. Yes, citizens imagine security in the broadest sense, that is, precisely as human security. Security, in their opinion, implies a set of conditions, circumstances and opportunities under which various spheres of public life fully function and create comfort and a sense of security among citizens (Mikheieva et al., 2020).

Thus, for the inhabitants of these regions, security primarily consists of the following components: physical, financial security, health security, proper work of law enforcement agencies, freedom of political or civil views, safety of movement in their locality, and a number of others. This means that even in the immediate vicinity of an area of long-term conflict, citizens understand security as a big jigsaw puzzle that spans various areas of their lives and does not focus solely on the concepts of ending the war.

5 THE INSTITUTIONAL PROVISION OF HUMAN SOCIAL SECURITY AND ITS COMPONENTS

Today, the current state of the social sphere is a crisis and threatens human social security, produces labor poverty, a decrease in the economic activity of the able-bodied population and the expansion of economically forced labor, the stratification of the population, the imbalance of the labor market, and, accordingly, reduces the efficiency of the functioning of the complex of social institutions.

The disadvantages of institutional support for the development of the human social security system are as follows:

- lack of prerequisites for ensuring expanded reproduction of high-quality and competitive labor force through the formation and implementation of national demographic, migration, career guidance and educational strategies;
- low level of functioning of the social partnership system, the role of trade unions in resolving conflicts between organizations representing different interests in society through negotiations and reaching compromises with the participation of local executive authorities;
- excessive regulation of labor relations at the micro level, which limits the resilience of social institutions at the regional and national levels;
- the imperfection of the mechanisms of state support for the entrepreneurial initiative of citizens; low level of economic activity of the population;
- the imperfection of the activities of state authorities to address the problem of illegal labor migration of citizens of Ukraine outside the country;
- the unresolved problem of organizing a unified national system of social, medical and pension insurance for the population;
- lack of experience in carrying out structural reform of the labor market by local government bodies;
- insufficient level of autonomy of local executive authorities and local governments in decision-making on the development of social infrastructure.

In general, the existing system of social security is characterized by a high level and significant scale of institutional threats, which leads to the development of directions for its strengthening (figure 2):

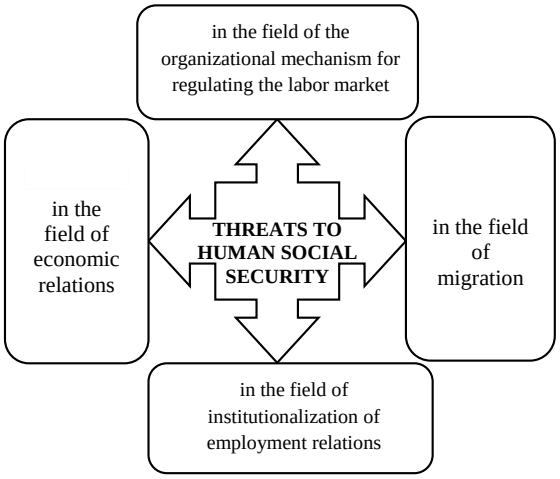

Figure 2: Threats to human social security (Iliash, 2011).

- in the field of economic relations:
  - increasing the efficiency of the motivational component of the shadowing of labor, which consists in further reducing the tax burden,

simplifying tax legislation and regulating economic activity, along with improving the quality of public services.

- the introduction of effective methods of attracting workers to various forms of economic activity, which will allow the legalization of hired labor under an employment agreement;
- development of a regional sectoral program for creating and maintaining jobs in the agro-industrial complex, the implementation by regional employment centers and local governments of social expertise of all investment and other regional targeted programs in terms of their impact on the creation and preservation of jobs in the rural economy; in the field of institutionalization of employment relations:
- a decrease in the number of forcedly created informal jobs due to a revision of the monetary and non-monetary costs of employers associated with the hiring and dismissal of the workforce;
- active informing the public through the media about social vulnerability in case of non-registration of labor relations with the employer officially, as well as the main articles of the current legislation to which employees are entitled.

• in the field of the organizational mechanism for regulating the labor market:

- strengthening state supervision and control over compliance with the requirements of labor legislation
- the creation of a regional system of labor courts, the activities of which will allow employees to assert their rights easier and faster, eliminate excessive red tape in the consideration of cases, and ensure their prompt and impartial consideration;
- introducing specialists into the circle of social partners who could offer an adequate methodology for calculating the tariff scale, taking into account the characteristics of types of economic activity and individual enterprises, taking into account the differentiation of levels of regional development;
- the creation by the state and regional authorities of appropriate initial conditions for the legalization of virtual labor capital, which will increase the opportunities for the development of the economy of border regions, significantly increase the competition of specialists in the field of intellectual and information services;

• in the field of migration:

- ensuring a high level of employment of the population through the formation of a ”flexible” labor market in Ukraine through the development of a joint action plan for the allocation by individual EU members of a quota for the employment of citizens of Ukraine;
- ensuring legal protection of domestic workers abroad by intensifying work in this direction by the Ministry of Foreign Affairs. If the introduction of such control is recognized, consider creating a specialized body of state administration (State Agency), whose competence included issues related to the employment of Ukrainian citizens in the EU member states;
- strengthening legal protection and providing social guarantees to labor migrants during their stay abroad, subject to return to their homeland; providing assistance at the state level to protect the interests of labor migrants in resolving labor conflicts with foreign employers.

6 THE LEGAL PROVISION OF HUMAN SOCIAL SECURITY

According to article 25 of the Universal Declaration of Human Rights, “everyone has the right to such essential things as food, clothing, housing, medical care and social services” (Con, 1996). The Universal Declaration of Human Rights, international covenants on civil and political, economic, socio-cultural rights legally guarantee citizens the right to life, inviolability of the person, social protection, freedom of opinion and belief, education and protection of social status (Dec, 1948). The rights, freedoms and duties of citizens are a necessary condition for the effective functioning of society and are subject to its cultural, material and spiritual norms.

A person, his life and health, honor and dignity, inviolability and security, in accordance with Article 3 of the Constitution, are recognized as the highest social value (Con, 1996). That is why social security is given special attention. It plays a key role in the entire system of national security. As a social state, Ukraine recognizes a person as the highest social value, distributes public wealth in accordance with the principle of social justice and takes care of strengthening civil harmony in society. According to part 4 of article 13 of the Constitution of Ukraine, the state ensures the social orientation of the economy, which is the basis for the realization of social rights of citizens, in particular to social protection and an adequate standard of living.

Ukraine seeks to implement the constitutional provisions that define it as a social and legal state. Citizens of Ukraine, in accordance with Article 46 of the Constitution of Ukraine, "have the right to social protection, including the right to be provided for them in case of complete, partial or temporary disability, loss of a breadwinner, ... in old age". This right is guaranteed by compulsory state social insurance (Con, 1996).

7 FOREIGN EXPERIENCES IN ENSURING HUMAN SOCIAL SECURITY

The social security of a person presupposes the presence of three models: European, American and domestic. According to the Association Agreement between Ukraine and the EU, Ukraine has chosen the European integration course, that's why it is advisable to consider the European model of social security and the possibilities of its application in Ukraine. At the same time, the American model has its own characteristics that may be useful for Ukraine (figure 3):

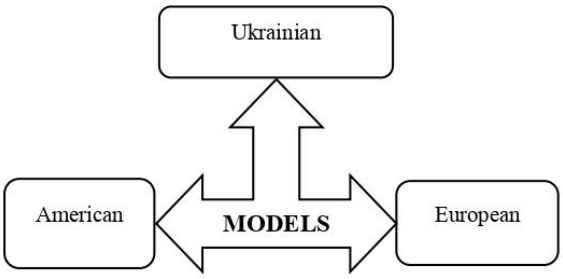

Figure 3: Models for ensuring human social security (Halytsa and Hetman, 2017).

1. European model of ensuring social security is characterized by high minimum living standards; flexibility in defining the "parameters" of social security; gender neutrality; contains a wide range of protective measures in the event of social threats; has an extensive list of unforeseen social circumstances, significant institutional support for socially unprotected segments of the population.

   Taking into account the experience of other countries, we believe that Ukraine should pay attention to the following issues:

   (a) Including the norm of public democratic control in all adopted documents. A democratic political system and democratic control of the armed forces play an important role in preparing for NATO membership. For example, Lithuania fully complied with all the requirements, and this was legally proven. The norms of public democratic control are indicated in all adopted documents (Fundamentals of Lithuanian National Security, the Law on the Organization of National Defense and Military Service, the Military Defense Strategy, the National Security Strategy, the Military Strategy).

   (b) The importance of the socio-economic development of national security is recognized in all strategic documents. In Georgia, the attentiveness of the socio-economic development of national security is recognized in all strategic documents. Thus, the National Security Concept of Ukraine (President of Ukraine, 2021) notes that sustainable economic development is a key condition for ensuring the country's national security. The National Security Concept of Ukraine notes the threats regarding low employment and economic backwardness, namely: social stratification, the absence of a middle class, an increase in the crime rate. Thus, improving the socio-economic living conditions of the population has become a key component of Georgia's security (Lebanidze, 2017; Sydorchuk, 2019).

2. American model of ensuring social security is based on the predominant financing of the provision of unforeseen threats; has fixed social security "parameters" and clearly defined social contingencies; characterized by the alternative choice of the social model of protection.

3. Ukrainian model of ensuring social security is fragmented: from a legal point of view, it is systemic and complex from the point of view of the regulatory framework, and in fact, it is ineffective due to the bureaucracy of procedures for providing social assistance to all categories, the lack of the necessary amount of funds for social assistance through demographic and migration imbalances and imbalances in the labor market, reinforced by an unformed social infrastructure.

4. The genesis of the mechanism for ensuring social security in the European and American models is characterized by the sequence: "social guarantees $\rightarrow$ social obligations $\rightarrow$ social security $\rightarrow$ social security", and the genesis of the mechanism for ensuring social security in the domestic model occurs in the opposite direction (Halytsa and Hetman, 2017).

The European Code of Social Security is the main normative document of the Council of Europe in the field of social security (ECS, 2022a). Although the

Code was approved in 1964, it is a valuable tool in defining common European social standards that can be used in the process of reforms that are taking place today in many European countries (especially in Central and Eastern Europe). The main idea of these legal instruments is to create a social security model based on social justice that is unique for all European countries. According to this model, the socially unprotected strata (those who cannot earn a living due to illness, old age, unemployment, work injury, occupational diseases, pregnancy and childbirth, disability or death of the breadwinner) should be guaranteed by the state a decent standard of living and support from society.

According to this code, the right to social security is enshrined in one of the main human rights documents of the Council of Europe – the European Social Charter (ECS, 2022b). The ratifying states are obliged to maintain the social security system at a satisfactory level. Thus, the promotion of the European Code of Social Security is the main task of the Council of Europe to create common values for the social orientation of its member countries.

Unfortunately, war is always associated with various forms of violence against women and girls. When seeking refuge during conflicts, women and girls become even more vulnerable to violence, sexual harassment and rape. Women and girls who are moving out of conflict need special support and protection. The Council of Europe Convention on preventing and combating violence against women and domestic violence (Istanbul Convention) (Ist, 2011) therefore complements the 1951 Geneva Convention relating to the Status of Refugees (UNHCR, 2022) and requires its 35 member states to develop reception procedures and support services for asylum seekers. At present, the process of ratification of the Istanbul Convention must continue.

8 FEATURES OF THE INSTITUTIONAL AND LEGAL PROVISION OF HUMAN SOCIAL SECURITY IN CONDITIONS OF THE WAR

First, it is advisable to note the priority areas of the state's activities to ensure social security according to a survey of respondents (table 1).

Therefore, the state's top priorities are to prevent and minimize external and internal threats, as well as to implement a strategic course for the development of a social state.

Table 1: Measures taken by the state to ensure social security (nsa, 2018; Sydorchuk, 2019)).

No	Directions	% to the number of experts
1	Prevent and minimize external and internal threats	66.7
2	Implement a strategic course for the development of a welfare state	52.4
3	Ensure effective social management	44.8
4	Realize the social interests of the citizens of Ukraine	42.9
5	Develop and implement government decent work programs	27.6
6	Create opportunities to achieve the 2030 Sustainable Development Goals	24.8
7	Ensure the efficiency and fairness of the state social insurance system	12.4
8	Increase the position of Ukraine in international rankings of social orientation	8.6

The events of recent years have shown a serious crisis in the system of not only social, but also international security due to Russia's external interference in the internal affairs of independent states, attempts to destabilize their political systems and direct forceful seizure of foreign territories. The hybrid war that began in 2014 provided for a diverse and long-term destabilization of the socio-economic and political situation in Ukraine. Unfortunately, almost all international security guarantees for Ukraine turned out to be incapacitated in conditions where one of the guarantors acted as the aggressor. The social dimension of the occupation of part of the Donbass and the annexation of Crimea formed a number of new social problems: the protection of human rights and countering racial discrimination against the population of the occupied Autonomous Republic of Crimea, internally displaced persons (about 1,5 million), organization of their residence, employment, assignment of social benefits to them, pensions, administrative recognition of documents, issues of "political prisoners" and missing persons and their families, the procedure for admission to higher education institutions of applicants from the temporarily occupied territories, provision of ATO participants and others.

On June 19, 2020, the UN General Assembly approved Resolution 74/168 "Situation of human rights in the Autonomous Republic of Crimea and the city of

Sevastopol, Ukraine" (Sit, 2020), which condemned the temporary occupation by the Russian Federation of part of the territory of Ukraine – the Autonomous Republic of Crimea and the city of Sevastopol, confirmed the non-recognition of its annexation The war in the East of Ukraine and the annexation of Crimea negatively affected the social security of a person and requires the adaptation of the social policy of the state and the improvement of the mechanism for its implementation, taking into account the socio-economic state of the regions of Ukraine.

A new challenge for social security was the large-scale war of Russia against Ukraine, which began on February 24, 2022 (Hamaniuk et al., 2022). Thus, with the increase in the scale and duration of aggressive hostilities, an increasing number of threats arise related to the observance of the necessary social security, society suffers heavy losses in the form of human casualties, material damage, environmental destruction and the threat of an ecological catastrophe. Social security cannot meet the principles of social solidarity, responsibility and partnership, resist external and internal existing and potential threats and provide social protection and conditions for improving the quality of life. The main prerequisite for observing human social security is to strengthen the power of the Armed Forces of Ukraine. Ukraine continues to follow the course of Euro-Atlantic integration and membership in NATO, strives to become in the future an element of a new European security architecture, where its vital interests will be ensured collectively with the direct participation of Ukraine itself. Without joining the North Atlantic Alliance – a system of collective security, Ukraine will not have effective levers of influence on decision-making in the future, taking into account its national interests.

9 DISCUSSION AND LIMITATIONS

9.1 Discussion

On the one hand, since the beginning of Russia's full-scale invasion of Ukraine, a significant amount of research using statistics and survey data has already been done. At the same time, not all information is significant, because under the information warfare affecting the quality of the received information, it is impossible to make a complete exhaustive assessment of the current situation in the country. Therefore, many aspects of human social security are debatable.

9.2 Limitations

Data for analysis is limited for a number of reasons: firstly, insufficient statistical data (some information is not available due to the fact that some official websites with information about the state of affairs of the government are closed due to cyber-attacks); secondly, not all people are willing to participate in the survey because of the psychological effects of war and post-traumatic stress disorder. In turn, this does not make it possible to conduct a comprehensive empirical study.

10 CONCLUSIONS

In our opinion, the current legislation on ensuring social security in Ukraine is ineffective and has a predominantly declarative nature. In the context of a deep socio-economic and political crisis, exacerbated by the instability and uncertainty of the situation in the East of the country, an increase in the level of well-being of the population, and even more so – the standard of living, strengthening social standards on the European model in the context of the "defensive" orientation of the budget and the galloping shadow economy, it seems difficult. However, these recommendations may include the following:

1. At the state level, it is necessary to ensure the integration of the social component into the strategy for implementing socio-economic reforms. The challenges of the time dictate the latest conditions for the formation of information support for management in the field of merit in the social security of the country.
2. Anticipate the norms of public democratic control in legislative and regulatory documents. The considered foreign experience allows us to take into account that in Lithuania the norms of public democratic control are indicated in all adopted documents, including the latest ones. In particular, according to the 2016 Military Strategy, democratic public control is a fundamental principle in the implementation of the military strategy, which notes that democratically elected civilian authorities make decisions on Lithuanian defense policy, the expansion of military potential and its use.
3. The modern system of public administration to ensure the social security of Ukraine should be based on and meet the Sustainable Development Goals, take into account the relevant conceptual

principles for the implementation of an appropriate national security system. At the same time, one should take into account the latest technological innovations in the developed countries of the world, European standards of social development. In this aspect, it is advisable to develop public immunity to military, economic, political, medical, and informational challenges in Ukraine. The long-term unresolved social problems in the vast majority of society acts as one of the main factors in the emergence and development of a number of threats in various segments of national security.

4. In today's conditions, Ukraine's movement towards the European model of ensuring social security is obvious. We consider it necessary to use predominantly the scientific achievements of domestic scientists to build the constituent subsystems of the existing mechanism for ensuring social security in order to restore the logical chain of the course of events in the sequence system: "social guarantees → social obligations → social security → social security".

11 RECOMMENDATIONS FOR FURTHER RESEARCH

Future research should include a comprehensive empirical study of human social security and ways for its improvement under the war. It is required to study the area of institutional and legal support of human social security in developed and developing countries. The matter is that we need the experience of developing countries to build a medium-term strategy for ensuring human social security, and developed countries — for a long-term strategy. Moreover, it is important to take into account the various situations that have appeared in the context of economic difficulties (financial and economic crises, pandemics and wars).

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Intensifying Use of Big Data for Emerging Markets in Society 5.0

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Keywords: Emerging Markets, The Theory of Welfare, The Theory of Needs, Big Data Technology, Loyalty Programs, Predictive Analysis.

Abstract: The use of Big Data is of particular interest to emerging markets, especially to business owners of enterprises selling goods and services. Big data is one of the opportunities to increase business results while meeting the needs of each client. Use of Big Data is especially actual during economic crises and in conditions of growing competition. Purpose – The main purpose of the article is to use Big Data technology for maximizing customers' satisfaction and business profits in Society 5.0 during crisis periods. Methodology – The study was based on utility theory Jules Dupuit, firm theory by Dionysius Lardner, the economics of welfare, theory Big Data. Findings – The low efficiency of discount loyalty programs is an incentive for the distribution of personalized programs has been proven. Such programs allow you to monitor the impact of the enterprise marketing policy in emerging markets on regular customers' behaviors. They also allow you to study preferences, purchasing power, and population migration. The impact of the rapid development of information technology has been investigated; in particular, the impact of Big Data technology on loyalty programs in Society 5.0 has been identified. Information component loyalty programs were classified. It will allow providing the most effective processing of consumer benefits information and increase sales, considering the features of crisis periods in economic development. Significance – The main competitive advantages of Big Data using have been identified. The importance of this technology for businesses has been proven. It should be especially used in the process of overcoming the crisis to form the optimal price for the product and maximize the results of the activity.

1 INTRODUCTION

After overcoming the consequences of the Coronavirus disease (COVID-19) pandemic and the consequences of the Russian-Ukrainian war there will be a need to take advantage of the competitive advantages of goods and services. It is necessary to be based on the basic concepts of economic theory. Can the concept of utility be used? Yes, the concept of utility was proposed by Jules Dupuit (Numa, 2016) who determined that the same product is sold at different prices to different customers. Moreover, differences in prices are irrelevant to the difference in costs. In addition, Dupuit partially discovers the conditions that are necessary for its implementation. A merchant can conduct such activities only if he is protected from competition, if he is a monopolist. This condition is necessary so that the seller can control the price. According to Dupuit's concept rising depends not only on the interests of the monopoly seller. Prices also depend on how buyers evaluate one or another thing. Based on utility theory the same product has different utility and different price that consumers are willing to pay for it. Since there are separate groups of buyers (rich, wealthy and poor), the monopolist is able to recognize these groups and consider the different willingness to pay for the product. Dupuit considered the theory of utility, primarily from the point of view of the consumer.

The issue of maximizing satisfaction of the needs and interests of individuals was studied by another

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British engineer and economist Dionysius Lardner almost simultaneously with Dupuis. Lardner (Hooks, 1971) analysed the possibilities of maximizing income from the perspective of the theory of the firm. He argued that price competition can be used as a means by which a firm is able to maximize profits. The analysis of railway tariffs allowed him to summarize the practice of their differentiation according to the distance and nature of the carried goods. He explained this differentiation by differences in elasticity: the different demands for rail transport services and the heterogeneity of the transported goods. Lardner's real contribution is to reveal the role of demand elasticity in the process of meeting the end consumers' needs.

Why will we use the theory of the economics of welfare? Pigou (Pigou, 1920) formulated the general conditions for price competition and identified its three types in the work "The economics of welfare". According to Pigou's concept general conditions fully contribute to the implementation of price competition. This happens when the demand price for any unit of goods does not depend on the selling price of any other unit of goods. This is possible only when no unit of goods can replace any other unit of the same product.

For example:

- no unit of goods sold in one market can be transferred to another market;
- not a single unit of demand presented in one market can be transferred to another market.

However, to achieve such equilibrium states information about the benefits and the purchasing capacity of buyers is necessary. This information must be accumulated considering domestic and foreign markets. In practice, it is very difficult because there are a lot of analogy products. Therefore, after overcoming the consequences of the Coronavirus disease (COVID-19) pandemic and the consequences of the Russian-Ukrainian war, the struggle for the end consumer will gain unprecedented proportions in the world.

The basic element of success will be positive emergent properties, which are focused on the emergence and development of innovations, especially when it comes to the struggle for the end consumer and emerging economy (Dzhedzhula et al., 2022; Hurochkina et al., 2021; Hordei et al., 2021). Drivers of positive emergent properties are at a high level of human capital development. Considerable attention is paid to the study of the features of the innovative development of human capital in the conditions of developing economies, and each direction and sphere of functional implementation of this resource is detailed (Czyżewski et al., 2021; Czyżewski et al., 2022). The processes of realizing human capital in a developing economy are complicated by the consequences of the coronavirus disease (COVID-19) and the Russian-Ukrainian war. Since there are problems with the number of permanent persons and internally displaced persons both in the middle of the country and outside its borders.

2 LITERATURE REVIEW

Industry 4.0 will contribute to the emergence of a new Society 5.0. Innovative technologies of Industry 4.0 will contribute to the rapid recovery and overcoming the consequences of the Russian-Ukrainian war.

Fundamental provisions of formation Society 5.0 and implementation of innovative Industry 4.0 technologies are considered in a number of work. Kitsuregawa (Kitsuregawa, 2018) highlight the questions of how Japan is launching Society 5.0 and the vision for a future smarter society. The work of Aquilani et al. (Aquilani et al., 2020) is devoted to the advanced manufacturing solutions, augmented reality, the cloud, and big data in the emergence of a new level of social development. Rahmanto et al. (Rahmanto et al., 2021) note the potential of huge advantages of big data technology in the emergence of a new level of social development and a breakthrough revolution in people's lives thanks to the use of technologies taking into account the humanitarian aspect.

Foresti et al.; Hayashi and Nagahara (Foresti et al., 2020; Hayashi and Nagahara, 2019) highlight the role of artificial intelligence in the functioning of automated planning and data analysis with the help of smart programs, smart infrastructure, smart systems, and smart networks.

Ellitan (Ellitan, 2020) focuses on the lack of HR (human resources) skills and the existing problem of security of communication technologies, and the inability of stakeholders to change, while in society 5.0 there is a clear priority due to the reliable and stable operation of production machines, which in turn leads to the negative consequences of worker losses places through automation. for the rapid adaptation of human capital for the benefit of improving public and business services, achieving a high level of literacy in working with data and its data analysis is an important condition. Simatupang (Simatupang, 2020) noted that the slow progress of Society 5.0 can be achieved through the development of integrated information technologies in universities and education. De Felice et al. (De Felice et al., 2021) noted that in order to achieve Society 5.0 it is important to manage the transition and identify the enabling factors that

integrate Industry 4.0. According to Önday (Önday, 2019), digital transformation creates new values and becomes a pillar of the industrial policy of many countries. Therefore, in Society 5.0, the basis of quality functioning is the achievement of convergence between physical and cyberspace. But it should be noted that the key drivers of the implementation of Industry 4.0 in Society 5.0 will contribute to rapid recovery in the post-war period, new economies will emerge, the only question will be the transfer of technologies for recovery and adaptation at the fastest pace.

3 METHODOLOGY

If you determine the level of demand in various market segments and in the markets of various countries, you can set an individual price for each unit of a homogeneous product, which will be equal to the price of its demand. This price is called the reserved price of the buyer. In its pure form, such a pricing policy is difficult to implement. The company does not know the reserved price of each buyer, but also cannot know its level from the buyer, since it is in his interests to reduce its value. It is the lack of information that does not allow the full introduction of perfect price competition and the largest financial effect.

The options (based on the collected data) for setting different prices for certain consignments of goods in accordance with the same demand function are used today. In practice, it often takes the form of various kinds of discounts (depending on the size of purchases, prepaid periods, etc.). In this case, the monopolist increases the volume of sales, and the consumer can achieve certain economies of purchase volume.

Differentiation of buyers into groups with different demand functions and subsequent pricing for each such group occurs separately during market segmentation. Segmentation is usually carried out by gender, age, income level, social status. There is the practice of setting different prices for students, senior citizens, people with disabilities and people of working age. Segmentation of end consumers is being made considering price and non-price ways of increase influence on sales (figure 1), which are reflected in loyalty programs.

However, the discount loyalty programs have some disadvantages:

- the ability to saturation and, consequently, decrease the efficiency of use;
- the complexity of how to form a group of supporters as well as the completion of the closure of the current program;
- the remoteness of non-regular customers and the usual price overpricing.

Nowadays discount accumulators and bonus cards are mostly used. Among the reasons that led to a change in the accounting policies of many enterprises there is a possibility of:

- the creation of various offers for various groups of clients;
- provision of discounts in the form of a certificate is an incentive for the client to return to the purchase of well-known goods and services;
- tracking the movement of regular customers and changing their preferences.

Introduction of such loyalty programs became possible thanks to the rapid development of information technologies that are capable to solve new problems. In addition, these cards can significantly reduce the turnover of small bills. But the main feature of these changes is the personalization of discount programs.

Personalization of seller-buyer relationships, using data mining (OLAP technology), allows you to analyze the dependencies of any values contained in the database and respond to the situation quickly. Important information for the seller is not only attracting new customers, but also controlling relationships with regulars. Firstly, the sales increase may be a consequence of a successful advertising company and, secondly, sales decrease for personalized discount cards is a consequence of low level of service, which will lead to a sharp decrease in sales in the medium and long term.

Currently, in order to increase the effectiveness of consumer segmentation the enterprise is trying to group them according to the level of the product value perception. In this case consumers are allocated:

- price-sensitive and thus easily change suppliers;
- sensitive to the quality of goods and services;
- are focused on creating long-term relationships and, as a result, strive to establish long-term partnerships to improve the quality of goods and services.

Internet trade has the greatest relevance during the lockdown. It is devoid of such shortcomings that are characteristic of the real sector of the economy:

- is not strictly connected with the territory of the physical existence of the consumer;
- can be carried out without any territorial restrictions;

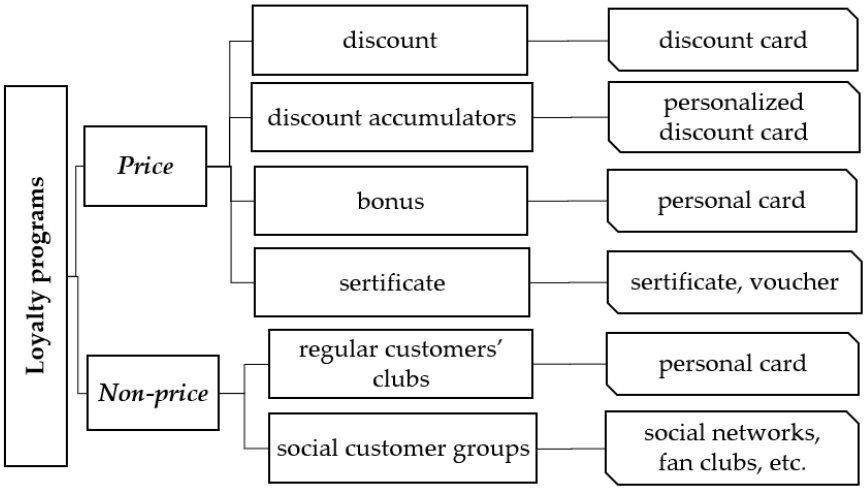

Figure 1: Classification of loyalty programs.

- the rapid development of the information society and information growth gave impetus to the development of new methods of its implementation.

In particular the Big Data theory is rapidly developing (Market Research Future, 2022). The term "Big Data" usually refers to a series of approaches, tools and methods for processing of structured and unstructured large volumes and the different nature data to obtain a consumer acceptable result. The introduction of the term "Big Data" is associated with Clifford Lynch (Lynch, 2008) who was an editor of Nature magazine and prepared a series of topical works. Quite often the "triple V" criterion is used to describe "Big Data": volume, velocity, variety. Some leading manufacturers of business intelligence software, such as SAS (SAS Institute Inc, 2022), additionally use two more: variability and complexity. In addition to growing speeds and data varieties, data flows can also be characterized by periodic peaks. Such peak data loads can be difficult to manage. It is worth to note the complexity factor as the most important factor when you are working with Big Data. While increasing the amount of data to variable n, the number of links between them grows in proportion to $n!$ (n factorial). So the problem is not limited only to the processing of large amounts of data but also requires an additional solution to the problem of analyzing connections' $n!$.

To identify a consumer on the Internet data for analysis is needed. The profile of the network is formed not only with the registration data on particular Internet resources but also activity in social networks, forums, blogs and the like. Thus, data reflecting the user is unstructured.

4 RESULTS

Leading corporations have developed platforms for big data business analytics (Market Research Future, 2022). In particular IBM, creating a full profile from social network data in the Big Data Analytical System, uses all the data that is more or less related to a specific consumer (table 1). At the first stage analysis of the texts takes place, at the second the linking of attributes takes place, at the third formation of statistical models and at the fourth formation of business logic take place.

Table 1: The data structure that is used to form a complete social user profile.

Full social customer profile	Personal characteristics	Identifiers
		Interests
		Social status
	Relationships	Personal
		Business
	Chronological activity	Purchase intention
		Current location
		Feedback on products and services
		Incident
		Loyalty facts
	Goods and interests	Personal relation to goods
		Shopping history
		Recommendations
	Politics	Attitude to power
		Political views
		Perception of reform
	Life events	Personal
		Reactions to events

Economic-mathematical modeling of the socio-

economic system based on online Big Data algorithms makes it possible to predict consumer behavior based on the identification of business logic and to form a consumer profile in the decision-making system. This method is traditional, but the selection of characteristic functional features for forecasting efficiency and optimization of Slick-Through-Rate forecasting processes is special in view of machine learning as a tool for economic and mathematical modeling of the management decision-making system.

Taking into account the presented data structure of the full profile of a social network user and the model of Big Data online algorithms, we have the possibility of flexible targeting of the target audience, adaptation of advertising content in accordance with user interests, the possibility of forecasting the effectiveness of advertising and its impact on consumer behavior. In addition, when building a model of Big Data algorithms, it is worth taking into account traffic segmentation and the Real-Time Bidding Exchange RTB auction (corresponding to the business logic of the consumer).

The use of Big Data in e-commerce provides such competitive advantages:

1) customer service: Big Data helps to give the consumer a sense of self-worth because his needs are maximally met by creating a certain connection between him and the brand. This cultivates consumers' loyalty and influence on their emotional level;
2) dynamic and point pricing: analysis of market data allows you to set an attractive price for each specific consumer;
3) personalization: in the process of analyzing consumers' information, personalized solutions are offered that become a competitive advantage for the client;
4) predictive analysis: Big Data allows you to carry out medium-term forecasting in the market and respond accordingly to possible changes in the market environment.

An example of this approach can be an application developed for the clothing brand Free People which provided sales growth of 38 percent (Dishman, 2013). The application allows users to discuss the latest collections, share their photos on Pinterest and Instagram social resources and vote for the best photos. This interaction is an example of the monetization of accumulated data by retailers using social platforms. Point discounts of Internet commerce can be divided by analogy with traditional commerce into two types depending on the technology that is used. The first type is personalized which provides for mandatory registration on a web resource, the second is not personalized (does not require registration). The first option of a point discount is for a price offer based on customer data, a history of web surfing (viewing products on a store page) and purchase history. Retailers often use social media accounts to register. It simplifies the registration procedure and gains access to user data. This significantly increases the amount of data to be analyzed.

Based on the data (table 1) on using Big Data, a consumer profile is formed and its segment affiliation is determined. In the future the client is offered an individual price offer. The price that is offered is minimal in order for the fact of purchase. In addition, goods are offered in accordance with the target audience. In other words, an individual approach to proposals is formed based on the analytical processing of unstructured data.

For convenience we have built EPC diagram (Software AG, 2022), which is often used to describe the workflow in ArisExpress environment (figure 2). If the visitor is not a consumer of goods and services, HTTP-cookie analysis of the web page is carried out that allow carrying out authentication, storage of personal user preferences and settings, session state tracking of user access, maintain user statistics.

It is also possible when there is not enough data to determine the profile of the visitor. This may be due to both the low activity of the Internet user and his conscious reluctance to "external tracking". One such way is to use an anonymous session. In this case the basic offers are determined by the system.

For machine learning target audience targeting, we use the Datch approach, taking into account the social network user profile, to build a model of online Big Data algorithms. The Datch approach is based on two-level testing of Big Data algorithms: training dataset and test dataset. The condition of the model is the constancy of the data of the decision-making system over time. At the same time, the dynamism of the system and the resonance of news on the website can become an emergent property of the socio-economic system, which will contribute to a further change in the trend. The model of Big Data algorithms for the task of predicting CTR is based on the systematization of the modeling process by stages and on a certain set of parameters of the data structure of the complete profile of a social network user.

$$W_{sc_{p+1}} = argmin \sum_{i=1}^{t-1} v(w_p, w_r, w_{ch}, w_{gi}, w_{pol}, w_l) + R(w_p, w_r, w_{ch}, w_{gi}, w_{pol}, w_l) \quad (1)$$

Figure 2: Structurally Logical Pricing Scheme in an EPC Chart.

where:

$W_{sc_{p+1}}$ – function social customer profile;

$v(w_p)$ – loss function for optimization Personal characteristics (Identifiers, Interests, Social status);

$v(w_r)$ – loss function for optimization Relationships (Personal, Business);

$v(w_{ch})$ – loss function for optimization Chronological activity (Purchase intention, Current location, Feedback on products and services, Incident, Loyalty Facts);

$v(w_{gi})$ – loss function for optimization Goods and interests (Personal relation to goods, Shopping history, Recommendations);

$v(w_{pol})$ – loss function for optimization Politics (Attitude to power, Political views, Perception of reform);

$v(w_l)$ – loss function for optimization Life events (Personal, Reactions to events).

$R(w_p)$ – regularization function Personal characteristics (Identifiers, Interests, Social status);

$R(w_r)$ – regularization function Relationships (Personal, Business);

$R(w_{ch})$ – regularization function Chronological activity (Purchase intention, Current location, Feedback on products and services, Incident, Loyalty Facts);

$R(w_{gi})$ – regularization function Goods and interests (Personal relation to goods, Shopping history, Recommendations);

$R(w_{pol})$ – regularization function Politics (Attitude to power, Political views, Perception of reform);

$R(w_l)$ – regularization function Life events (Personal, Reactions to events).

The loss function for optimizing the profile characteristics of a social network user will have the following form:

$$v_t\left(w_p,\ w_r, w_{ch},\ w_{gi},\ w_{pol}\ , w_l\right)\ = \|w - x_t\|^{\ 2} \qquad (2)$$

Under the conditions of a linear loss function in order to optimize the characteristics of the social net-

work user profile, the formula will have the following form:

$$v_t(w_p,\ w_r, w_{ch},\ w_{gi},\ w_{pol}\ , w_l)\ = \langle w, x_t \rangle \quad (3)$$

Under conditions of activation of emergent properties in the socio-economic system, such as dynamic system changes or trend changes under the influence of high-profile news on the site, which contribute to the manifestation of binary dependence at the bifurcation point, the function will have the following form:

$$\begin{aligned} &v_t(w_p, w_r, w_{ch}, w_{gi}, w_{pol}, w_l) = \\ &(\sigma\left(\left(w_p,\ w_r, w_{ch},\ w_{gi},\ w_{pol}\ , w_l\right) x_t\right) - y_t) x_t \end{aligned} \quad (4)$$

σ – sigmoidal function:

$$\sigma(\alpha) = \frac{1}{1+e^a} \quad (5)$$

With the activation of emergent properties in the socio-economic system, the regularization function will have the following form:

$$R(w_p,\ w_r, w_{ch},\ w_{gi},\ w_{pol}\ , w_l)\ \ =\ \ \frac{1}{2_n}\|w\|^{\,2} \quad (6)$$

Under the conditions of if $\eta > 0$, then the iteration of the machine learning algorithm will include a stepwise gradient descent algorithm and will look like:

$$\begin{aligned} &w_{sc_{p+1}} = -\eta \sum_{i=1}^{p} z_i = Wsc_p - \eta z_i = \\ &Wsc_p - \nabla v_t(w_p, w_r, w_{ch}, w_{gi}, w_{pol}, w_l) \end{aligned} \quad (7)$$

The resulting formula for optimizing management decisions, taking into account the parameters of the data structure of the full profile of a social network user, will look like this:

$$w_{p,i} = \begin{cases} 0 & |x_i| \le \varepsilon_1 \\ -\left(\frac{\beta+\sqrt{n_i}}{\alpha}\right)(x_i - sign(x_i)\varepsilon_1) & |x_i| > \varepsilon_1 \end{cases} \quad (8)$$

where x and n iteration parameters, $\varepsilon_1,\ \varepsilon_2$ are regularization intensity parameters according to the selected type and α, β – are input parameters characterizing the learning rate.

Since, based on the above, in order to achieve the optimum at each step of the algorithm execution, the optimal decision is made and the previous ones are not foreseen, then this model belongs to the Greedy algorithm. A characteristic feature of these algorithms is relative simplicity and speed of execution.

This technique of point discount has been actively developing over the past three years. One of the first companies that offered this service was Freshplum whose founder was Sam Odai. Later Freshplum joined the TellApart company (SAS Institute Inc, 2022), which operates in the market of services for online stores. Moreover, the algorithm for potential customers' selection of this company uses a number of "non-standard" indicators such as: place of residence (city center or outskirts), weather, etc. This allows you to increase the likelihood of making a purchase up to 36 percent (Tanner, 2014).

For the first time the analysis of differential pricing in online stores was conducted by the The Wall Street Journal. The editors conducted a study (Valentino-DeVries et al., 2012) of pricing in 200 online stores.

The economic situation in the world is extremely dependent on the geopolitical risks that can now be observed (for example the corona virus pandemic and the consequences of the Russian-Ukrainian war). Therefore, the widespread use of Big Data concept may increase the profitability of enterprises. The use of Big Data methods will become an additional source of budget revenues after taxation. This will maximally satisfy the needs of consumers whose incomes have recently been declining due to devaluation and inflationary processes. In order to increase competitiveness of European goods and services markets the use of big data is a mandatory requirement of our time.

5 CONCLUSIONS

The economic situation of all countries of the world is extremely dependent on the geopolitical risks that can now be observed (for example, a COVID-19 pandemic and the consequences of the Russian-Ukrainian war). Therefore, the widespread use of Big Data basics will increase the profitability of enterprises. The use of Big Data methods will become an additional source of budget revenues, after taxation. This will maximally satisfy the needs of consumers whose incomes have recently been declining due to devaluation and inflationary processes. In addition, in order to increase competitiveness in European markets for goods and services, the use of big data is a mandatory requirement of our time. The use of the presented economic-mathematical model will make it possible to reach the optimum at each step of the algorithm execution, the optimal decision is made according to the Greedy algorithm type, which is characterized by a fairly simple feature and speed of execution.

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Flexible Evolutionary Model of Machine Learning of Organizational Capital Development Strategies with Optimization of Spent Resources

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Keywords: Q-Leaning, Organizational Capital, Strategy, Q-Leaning, Optimization of Organizational Capital, Concept of Alternative Selection.

Abstract: As part of the follow-up, the conceptual pipeline was developed to the stage of machine learning Q-leaning with the method of eliminating the most effective strategy for the development of organizational capital in the structure of intellectual capital and increasing the reliability of taking away the results. In the final work, the modeling of alternative strategies for the development of organizational capital with the alternatives of machine learning was modeled. This simulation made it possible to simplify the search and development of options for strategies for the development of organizational capital, real alternative ways, and to simplify management decisions. For a more correct operation of machine learning, coefficients were introduced that affect the decision-making by machine learning. Results indicate that the capital of the strategy is the acquisition of innovative information potential and the capital of alternatives without intermediary victorious main functions of formation and the establishment of mechanisms for managing intellectual capital in the aggregate with other types of capital in them.

1 INTRODUCTION

The modern economy practically proves the effectiveness of intellectual capital as one of the most effective. The concept of intellectual capital is broader than the concepts of intellectual property and intangible assets. At the same time, it is close in meaning to the concept of intangible capital, which has been used in works on economic theory and econometrics since the beginning of the 1970s (Brooking, 1996).

Daum (Daum, 2002) gave the definition of intangible capital based on connections structured knowledge and abilities that have the potential to develop and create value.

Leontiev (Leontiev, 2002) defined intellectual capital as the value of the set of intellectual assets available to the enterprise, including intellectual property, its natural and acquired intellectual abilities and personnel skills, as well as accumulated knowledge bases and useful relationships with other entities.

Roos et al. (Roos et al., 2005) defined intellectual capital as all non-monetary and intangible resources that participate in the creation of the organization's value and are fully or partially controlled by it.

Intellectual capital is difficult to research and calculate its value due to the difficulty in determining the components that belong to it. However, intellectual capital can be divided into several capitals that are part of it: human capital, organizational capital, customer or consumer capital.

Each component of intellectual capital can be structurally detailed:

1. Human capital, the value that the company's employees bring through the application of skills, know-how and expertise. Human capital is inherent in people and can belong to an organization.
2. Organizational capital consists of: technological capital; branding capital; capital of business culture; capital efficiency of added economic value – EVA; capital of the strategy of attracting innovations of the information potential. The criteria for evaluating are manufacturability; productivity; innovativeness; cooperativeness; adaptability; efficiency.
3. Customer equity, consisting of elements such as customer relationships, supplier relationships,

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trademarks and trade names (which have value only through customer relationships), licenses and franchises.

Therefore, the presence of a multi-criteria approach to the application of intellectual capital creates the complexity of its assessment. If we consider the methods of measuring intellectual capital, the following are the most common four categories proposed by Sveiby (Sveiby, 2010): Direct Intellectual Capital Methods; Market Capitalization Methods; Return on Assets methods; Scorecard Methods. But each of them has certain disadvantages that should be considered in conjunction with machine learning methods. Then there is an opportunity to build a general mathematical model with a unified machine learning algorithm, and this affects the accuracy of estimates of all structural elements of intellectual capital.

2 RESULTS

If we consider the structure of Organizational Capital (OC) as a set of its qualities and properties, their ratios, which directly affect labor productivity, which increases the income for personnel, the company as a whole, society, and the nation, then there is an opportunity to cover all possible options for its evaluation.

1. Assessment of the level of manufacturability

Let's move on to the assessment of the properties of the components of manufacturability capital. We will use its structure, which consists in determining the share a_t^k of the t-th property in the formation of the k-th type of components of manufacturability capital (k_k^t), which allows us to establish the probable level of the k-th type of manufacturability capital:

$$KT_{t^k} = \sum_{k=1}^{n_{ip}} k_{k^t} * a_{k^t}, \tag{1}$$

where

KT_{t^k} – technological capital;

k_{k^t} – exploitation and repair manufacturability of the structure to k item for t-th indicator (materials, energy, labor, compatibility, etc.);

a_{k^t} – volatility of the injection of the t-th indicator for manufacturability of k item.

2. Capital assessment of business culture

$$CC_{k^t} = \sum_{k=1}^{n_{ip}} c_{k^t} * b_{k^t} \tag{2}$$

where

CC_{k^t} is the capital of business culture;

c_{k^t} – organizational and corporate culture of a certain business model of doing business according to the t-th indicator (liberty and democracy, monoactivity of the business culture type; polyactivity of the business culture type; reactivity of the business culture type, etc.);

b_{k^t} – the importance of the impact of the t-th indicator on the cultural capital of the k-th business model of doing business.

3. The efficiency capital of added economic value

The productivity of the production process has a significant range of properties, the characteristic features of which are formed and reflected by a significant network of indicators that have branched relationships of quantitative and qualitative capital assessment of performance. Among the important features of performance, the following should be noted:

- Activation of human heuristic abilities and structuring of discovered knowledge and verification according to the criterion of objectivity;
- Orderliness of the communication process for the exchange of information flows, emotions, social and individual values, economic interests;
- Formation and growth of the fundamental and market value of the enterprise as a criterion of performance.
- Identification and elimination of dysfunctions in enterprise management, which arise due to a malfunction.

Capital assessment of efficiency of added economic value. Performance is assessed as the level of intellectual leverage (LIL) and is calculated according to the formula:

$$LIL = \frac{\triangle EVA\%}{\triangle NOPLAT\%} \tag{3}$$

where:

$\triangle EVA\%$ is the rate of profit growth;

$\triangle NOPLAT\%$ is the growth rate of economic added value.

LIL – the degree of sensitivity of profit to changes in economic added value.

The level of intellectual leverage shows: how many times the growth rate of economic added value exceeds the growth rate of profit. This excess is provided with the help of the effect of intellectual leverage, one of the components of which is its differential (the ratio of the involved intellectual capital to its own).

4. The capital of the strategy of attracting innovations of the information potential

The information capital of the strategy or the capital of the strategy of attracting innovations of the information potential determines the trajectory of intellectual capital and the direction of the implementation of the proposed strategy within the framework

of the implementation of innovations of the information potential, which is aimed at increasing the value of capital and depends on the speed of updating this strategy. Informational capital and its potential act as investment capital to maximize the value of intellectual capital:

$$\left(\frac{\sum_{i=1}^{k} EVA}{ROI_{opt} - WACC} - CAPITAL\right) \rightarrow max \quad (4)$$

where

ROI_{opt} is the economic profitability of intellectual capital;

$WACC$ – weighted average interest rate of the involved intellectual capital;

$CAPITAL$ – the capital of the strategy of attracting innovations of the information potential.

5. Capital of turning knowledge into a result

The capital of the transformation of knowledge into a result declares the path of transformations from an idea to the formalization of knowledge in official documents and its structuring for communicative use (Porokhnya, 2009). Therefore, its components are the following indicators that reflect the characteristic properties of transformations: an idea as a creative and spiritual message, and the level of formalization of knowledge in official documents.

An idea has its own depth of penetration into the macro or micro world (Roos et al., 2005). Based on Einstein's thesis that the development of society requires the improvement of everyday thinking, it is appropriate to consider an idea-concept as a complex of properties and relationships that determine the characteristics of the image of the object of research. we can establish a connection between intellectual capital (figuratively speaking, the mass of intellectual substance that is at rest or in motion, that is, in its use) and the strategy of interaction of processes in an economic object and its results. The question arises, does the strategy have energy? It is known that the strategy has different value, that is, weight. Suppose that, like any economic potential, it has potential energy, and when the process of its realization takes place, it also has kinetic energy. That is, strategy is the energy of capital that goes to the realization of an idea-concept. Therefore, it can have its own dimension. Strategy, like any energy, consists of the energy of rest and the momentum of intellectual capital. As the speed of this impulse, we will take the speed of the generation of an idea-concept in the direction predetermined by the strategy. To measure images-properties, that is, the amount of intellectual substance, a unit is introduced, – image.

Any image of intellectual substance contains the same number of images-properties that reflect the properties of the object of the real world. For example, the number of images-properties that characterize a person is a constant value, a number that can be established experimentally, as Avogadro's number was established at one time (the principle of equivalence in nature). But each person has a different number of images-relationships characterizing his intellectual capital. This value of images-relationships, corresponding to intellectual capital, will be assigned the unit of measurement – intel. Intel measures the level (mass) of intellectual capital of a person, enterprise, state.

The definition of images-properties is a consequence of the same type of process properties during the realization of an idea-concept in time, which contain a certain number of these images in one unit. We denote the number of images-properties by N_{img}:

$$N_{img} = \frac{100}{image} - const \quad (5)$$

From here we can determine the amount of the level (mass) of the intellectual capital of the economic system, which corresponds to the capital of transforming knowledge into a result:

$$ic = \frac{N}{N_{img}} M_{ic} \quad (6)$$

where

N – the number of images-properties, respectively, ideas-concepts,

M_{ic} - the intellectual mass of image-properties per image-property for a specific phenomenon, intel / image.

The level of an idea-concept can be represented in four quantitative measurements with the introduction of a unit of measurement – id, which contains a certain integral number of images-objects that characterize the properties of this very idea-concept using established criteria:

- Elementary level (household, cognitive, which does not require the formation of new knowledge), where $id = 1$.
- The technological level associated with the emergence of new technologies, etc., where $id = 1000 = 1K$.
- Conceptual level containing new knowledge and discoveries, where $id = 1000000 = 1M = 1000K$.
- The planetary level is determined by the depth of penetration of human activity into the macro and micro world, where $id = 1000000000 = 1G = 1000M = 1000000K$.

$InfConvert_k^t$ – informativeness as a measure of usefulness. The level of structuring of knowledge of

special and general scientific terms and its verification according to the criterion of objectivity of the k-th type of the indicator of capital transformations according to the t-th component of this indicator.

$InfCap_k^t = InfConvert_k^t / TotalExp$ – the level of orderliness of the communication process for the exchange of information flows, emotions, social and individual values, economic interests of the k-th type of the indicator of capital transformations according to the t-th component of this indicator.

Evaluation of the capital of the transformation of knowledge into a result

$$CP_k^t = \sum_{k=1}^{n_{ip}} (ic_k^t + InfConvert_k^t + InfCap_k^t) d_k^t \quad (7)$$

where

CP_k^t – the capital of transforming knowledge into a result;

ic_k^t – the capital level of the transformation of knowledge into the result of the k-th type of the indicator of capital transformations according to the t-th component of this indicator;

d_k^t – the weight of the influence of the k-th indicator of transformations on the capital of the transformation of knowledge into a result according to the t-th component of this indicator of transformations.

For a preliminary analysis of the capital criteria, their importance, influence on the choice of the best alternative for the development of the properties of organizational capital, we will use the method of hierarchical comparisons when evaluating the level of priorities of alternatives, the results of which are shown in the table 1.

The structure of OK is primarily related to branding capital, which is the main relative indicator of the company's attractiveness on the market and to some extent attests to the fate of the firm's market capital, which is adjusted to its organizational, i.e., intellectual capital.

The relevance of the use of machine learning in the field of economics (Kobets and Novak, 2021) allows us to consider many aspects of the strategy for the development of organizational capital and ways to optimize the cost of resources for its development in different ways. Learning to find the most optimal and less resource-intensive way of developing organizational capital can be presented as a continuous cycle that will end only after the specified conditions are reached. (figure 1).

In the reinforcement learning algorithm, the agent's actions are directed to the steps to achieve success with a reward estimate. After $\triangle t$ steps into the next step, the human capital will decide some next step. The weight for this step is calculated as $\gamma^{\triangle t}$,

Table 1: Influence of criteria on a choice of alternatives (properties) of improvement of the level of capital.

Criteria	Properties				
	Intellectual	Communicative	Strategic	Cognitive	Innovative
Branding capital	0.14	0.12	0.14	0.1	0.09
Technology capital	0.12	0.14	0.13	0.14	0.1
Capital efficiency of added economic value	0.11	0.12	0.11	0.13	0.12
Capital of business culture	0.11	0.12	0.13	0.11	0.12
The capital of the strategy of attracting innovations of the information potential	0.1	0.12	0.13	0.12	0.1
General approach	0.11	0.12	0.13	0.115	0.11

where γ is the discount factor, which can take a value from 0 and 1 ($0 \leq \gamma \leq 1$) and has the effect of evaluating actions that are aimed at achieving the human capital goal. γ can be called the level of success in achieving the desired state by human capital, when the investment data changes at the $\triangle t$ step.

Thus, we can conclude that a function is required that will determine the quality of combinations of the state of human capital and the action aimed at it:

$$Q \div S \times A \to R. \quad (8)$$

At the beginning of training, Q is initialized, possibly with an arbitrary fixed value – 0. After initialization, at each moment of time t, the agent selects an action, observes a reward, enters a new state (that may depend on both the previous state and the selected action), and Q is updated. The core of the algorithm is a Bellman (Bellman, 1957) equation as a simple value iteration update, using the weighted average of the old value and the new information(Watkins and Dayan, 1992):

$$Q^{new}(s_t, a_t) \leftarrow Q(s_t, a_t) + \alpha \times (r_t + \gamma \times maxQ(s_{t+1}, a) - Q(s_t, a_t)), \quad (9)$$

where r_t is the reward received when moving from the state S_t to the state S_{t+1}, and $0 < \alpha \leq 1$;

Note that $S^{new}(s_t, \alpha_t)$ is the sum of three factors:

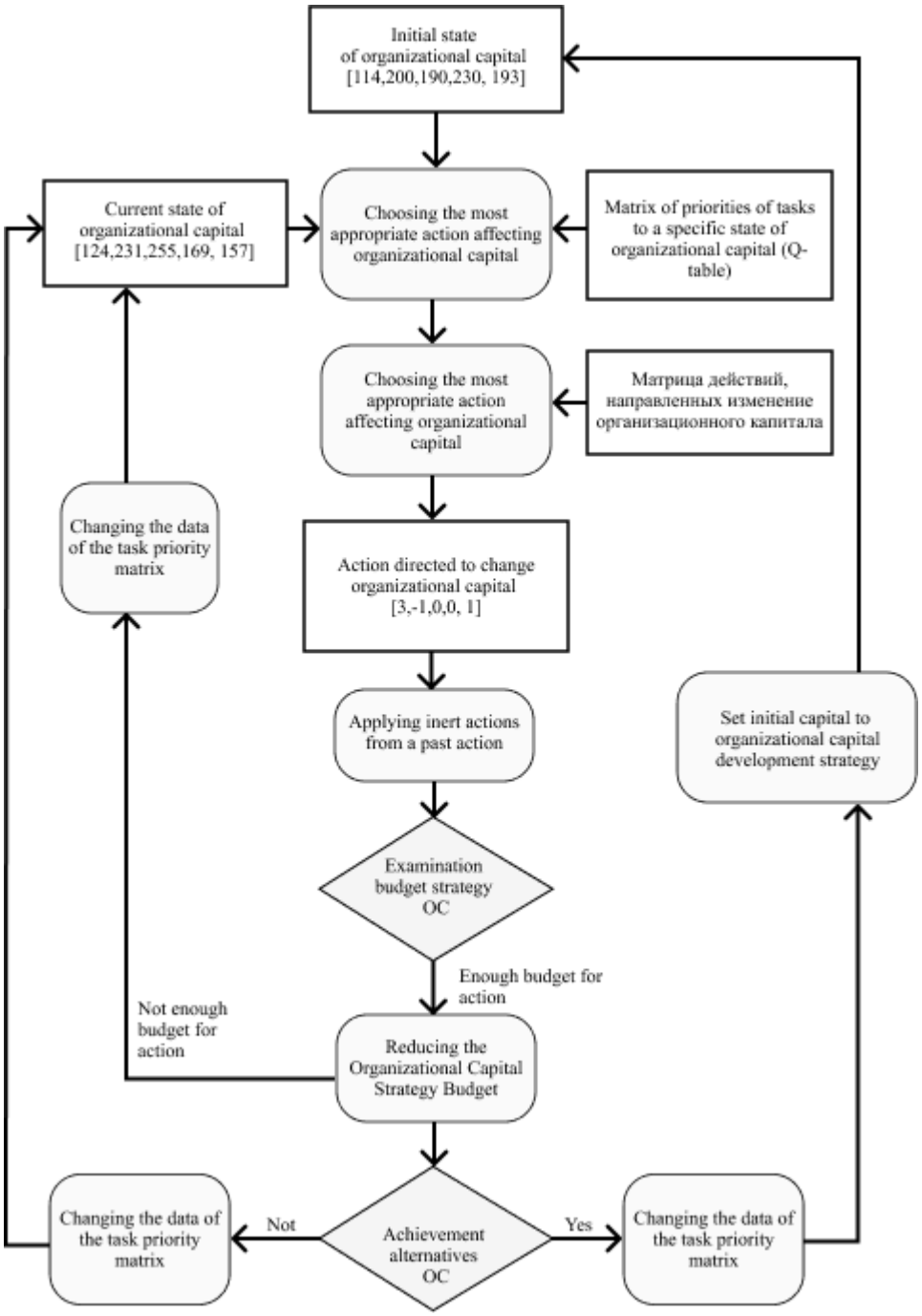

Figure 1: Machine learning of alternative development of human capital of the enterprise.

$(1-\alpha)Q(s_t,\alpha_t)$: the current value weighted by the learning rate. Values of the learning rate near to 1 made faster the changes in Q;

αr_t: the reward $r_t = r(s_t,a_t)$ to obtain if action a_t is taken when in state s_t (weighted by learning rate);

$\alpha\gamma\max Q(s_{t+1},\alpha)$: the maximum reward that can be obtained from state s_{t+1} (weighted by learning rate and discount factor).

Each action has its own parameters, and system changes can be limited by parameters that can be correlated with the required resource costs to apply the action chosen by machine learning. Thus, each iteration of training implies two possible effects:

1. Changes in the coefficient of effectiveness of the

action, depending on the state that the system acquires as a result of the application of the action.

2. Return of the iteration to the initial state due to non-compliance with the specified restrictions for machine learning.

For the application of Q-Learning, the following parameters were selected:

- Impact on the Intellectual Capital criteria
- Time spent in days
- Resource costs equivalent to monetary units
- The coefficient of the complexity of the action
- Risk ratio of failure to take action
- Inert influence on the system
- Coefficient of possibility of inert influence on the system

Each action parameter is used in the calculation of the effectiveness of the action taken at each training step. Applied properties of actions can be represented as a table of actions, which is presented in figure 2.

	IK									PIK					
Action	Branding Capital	Technology Capital	Value Added Efficiency Capital	Business Culture Capital	Implementation capital innovation information capacity	T	RE	WI	RoD	Branding Capital	Technology Capital	Value Added Efficiency Capital	Business Culture Capital	Implementation capital innovation information capacity	PP
1	1	3	0	1	2	24	40	0.3	0.3	0	0	0	0	1	0.3
2	0	0	1	2	0	12	120	0.1	0.4	0	1	1	1	0	0.1
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
23	T	T	T	T	T	40	240	0.3	0.12	1	1	1	1	0	0.5

Figure 2: Action properties used in machine learning with resource cost parameters.

Thus, at each iteration, the system calculates a promising system that has already been acted upon and recalculates the result of intellectual capital with new parameters.

Thus, we can say that the calculation of the effectiveness of the action is carried out according to the following formula:

$$AE = IK_{t+n}, \tag{10}$$

where

AE – action efficiency;

IK – the cost of intellectual capital;

IK_{t+n} — the cost of intellectual capital after applying the action.

So the value of AE will be rewards for moving to the next machine learning state.

$$Q^{new}(s_t,a_t) \leftarrow Q(s_t,a_t) + \alpha \times (AE + \gamma \times maxQ(s_{t+1},a) - Q(s_t,a_t)), \tag{11}$$

However, each action additionally has a time cost parameter for performing this action, which can optionally be included in the formula. For greater accuracy of calculations, you can use hours, days, months or quarters. In this case, integer values of days were used.

Thus, the new formula for calculating efficiency can be represented as follows:

$$AE = IK_{t+n} * T, \tag{12}$$

where AE – action efficiency, T is the time spent on applying the action

Also, an optional parameter can be resource costs, which are presented in monetary terms. To simplify the loads and quick calculations, all action parameters can be divided by a certain coefficient Mk. In this case, $Mk = 1000$.

Thus, if Action 1 has a resource cost (FE) of 1300000, then the resources spent can be represented as RE and calculated by the formula:

$$RE = \frac{FE}{Mk} * T. \tag{13}$$

Taking into account resource costs, the action efficiency formula will look like this:

$$AE = \frac{IK_{t+n}}{RE} * T. \tag{14}$$

The calculation of resource costs can also include the coefficient of complexity of performing an action (WI), which can be represented by a value in the range from 0.1 to 1.0. Thus, now the resource costs can be represented as:

$$RE = \frac{FE}{Mk} * T * WI. \tag{15}$$

Also, given the individuality of the systems to which actions can be applied, it is worth considering the risks of not performing an action (RoD) or its success in execution.

The risk of investing in organizational capital is the possibility that the accumulated organizational capital will not bring the expected return, will not be in demand in the market, or will not bring the expected return. This value can be represented as a range from 0 to 1. A low value of this coefficient means a low level of success of the action and its high risks. Given the risk ratio, the formula for the effectiveness of action can be represented as follows:

$$RE = RoD\frac{IK_{t+n}}{RE}. \tag{16}$$

The relationship of all parameters of intellectual capital does not exclude the influence of the development of some parameters on the possibility of developing other parameters as a result of these actions.

Thus, each action has the values of the inert development of intellectual capital and the coefficient of the possibility of this development.

Given these parameters, the formula for the effectiveness of actions can be represented as follows:

$$RE = ROD\frac{IK_{t+n}}{RE} + PIK * PP * RoD, \quad (17)$$

where PIK is the value of the possible inert development of intellectual capital, PP is the probability coefficient of the development of intellectual capital.

Thus, each iteration of training affects the value of intellectual capital by changing the values of its parameters. However, it is the efficiency values of the action that are written to the state table, not the cost of capital. Having an unlimited resource of investments, achieving the desired value of the cost of intellectual capital had a large set of action algorithms, but given the parameters of each of the actions, machine learning will find the most optimal algorithm for this system.

The development of Intellectual capital occurs with the choice of an alternative to which the capital must approach as a result of learning.

For more effective training and achievement of the most favorable conditions for achieving the desired alternative, development alternatives were introduced. Development alternatives are coefficients for each of the parameters of actions that affect the state of capital. Using the hierarchy analysis method, the following coefficients were introduced (table 2).

Table 2: Alternatives of the development method for managing the choice of effective action.

	Accelerated	Safe	Risky	Budgetary	Effective
IK	0.21	0.26	0.31	0.2	0.32
T	0.23	0.12	0.2	0.08	0.13
FE	0.12	0.12	0.12	0.09	0.12
WI	0.12	0.16	0.13	0.32	0.1
RoD	0.1	0.07	0.08	0.09	0.13
PIK	0.1	0.19	0.1	0.08	0.08
PP	0.12	0.07	0.06	0.14	0.12

For this study, a risky alternative of the method of developing capital for machine learning was chosen.

Thus, each iteration of learning and applying actions to the system will affect the state table and calculate its new values according to the following formula:

$$AE = (RoD\ a_5)\frac{IK_{t+n}\ a_1}{(FE\ a_3)\ (T\ a_2)} + (RoD\ a_5)\ (PIK\ a_6)\ (PP\ a_7) \quad (18)$$

After carrying out the calculations with the initial data, the results describing the strategy for investing in organizational capital shown in table 3.

Table 3: Factor of importance of action properties for learning.

IK	T	FE	WI	RoD	PIK	PP
a_1	a_2	a_3	a_4	a_5	a_6	a_7
0.31	0.2	0.12	0.13	0.08	0.1	0.06

It should be noted that the coefficients of capital alternatives and development alternatives affect value preferences and spending.

The first stages of training provide impressive indicators of cost optimization for investment in organizational capital. With an increase in training cycles, obtaining a better result becomes more rare.

The data in the table 4 and in the figure 3 show optimization costs of developing organizational capital to achieve the cost of organizational capital, taking into account the chosen alternative. It can be concluded that in order to achieve the best results, it is necessary to conduct a sufficient number of training cycles.

Table 4: Initialized data affecting machine learning training in the search for optimal investments in organizational capital.

Action number	Impact values on organizational capital					
	Salary	Branding Capital	Technology Capital	Value Added Efficiency Capital	Business Culture Capital	Implementation capital innovation information capacity
16637	2219	52	286	313	45	333
25352	1431	155	121	95	128	318
74521	725	157	151	54	138	340
168348	684	184	115	74	123	286
2236341	485	133	87	33	142	118
14330450	336	197	90	51	165	114
17735547	294	127	44	201	153	134

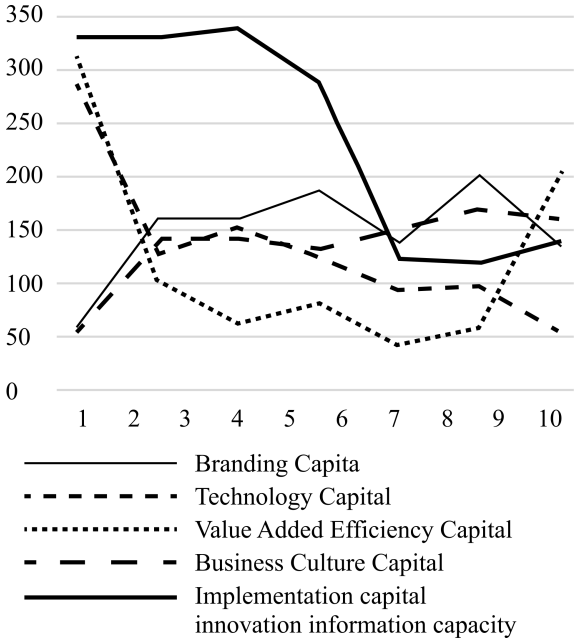

Figure 3: Machine learning of alternative development of organizational capital of the enterprise.

Thus, after each stage of learning new indicators, alternatives should be identified and calculations should be made that determine subsequent investments in human capital. It should also be borne in mind that each the alternative has its own characteristic features and characteristics, behavioral connections and influence on the choice of options capital investment.

Taking into account the dynamics of changes in results, it can be concluded that subsequent training cycles can bring more optimized costs. Figure 4 shows the optimization of the costs of organizational capital development, taking into account the same level of organizational capital development.

It is also worth noting that when the input data changes, machine learning will be able to rebuild and generate calculations and optimize the result better and faster than a person.

3 CONCLUSIONS

The study substantiates a conceptual approach to the application of Q-leaning in order to obtain the most effective strategy for the development of organizational capital in the structure of intellectual capital and increase the reliability of the results obtained.

Consequently, the capital of the strategy for attracting innovations of information potential and the capital of alternatives directly perform the main functions of the formation and application of intellectual

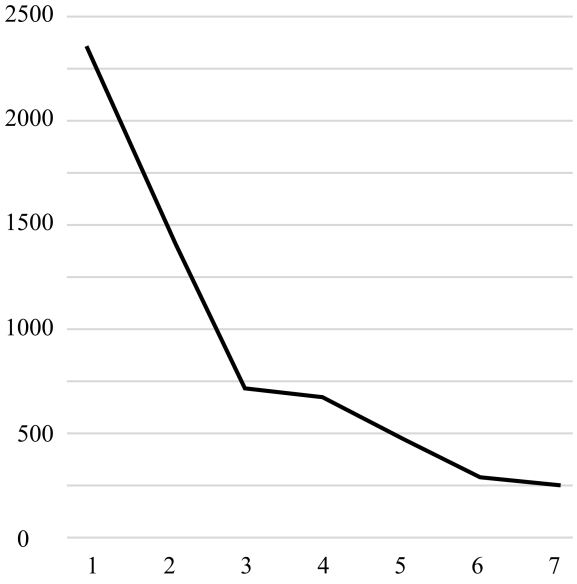

Figure 4: Machine learning of alternative development of organizational capital of the enterprise.

capital management mechanisms in conjunction with other types of capital and independently of them.

The main difficulty of this approach to choosing alternative solutions for finding options for using organizational capital is the correct selection of indicators of significance (return) of contributions to the development of types of organizational capital, on the basis of which systemic learning cycles occur. Such an approach can simplify the search and development of options for organizational capital development strategies, real alternative paths and simplify management decisions.

It is worth noting that training tuning with changing the training parameters, namely the amount of reward and the value of data optimization, training constraints, can achieve better results by accelerating training and therefore obtaining data on a more trained AI that can give better results.

Using machine learning to optimize organizational capital development costs is the best method. Speed, lack of subjectivity and the ability to quickly respond to external changes is an advantage over a person.

To improve the results, it is worth making adjustments to these actions and selecting the right alternatives for choosing actions.

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Force Majeure and Insurance of Risks of Economic Emergencies

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Abstract: The paper deals with the actual problem of developing new insurance products in the conditions of hybrid military actions and the application of economic sanctions. For modern Ukraine the "hybrid military actions" from the "neighbor-state" are actually for nine years. However, there are some legal issues on the way to a clear understanding of the difference between "insuperable force" and "force majeure". It is also caused by misreading of the legal system from the representatives of different sectors, despite a good history of national insurance companies formation and development. Thus, in the paper authors present the results of correct understanding and usage of mentioned categories, pay attention to risks with grants in project management, and unclose ways for development of new products according to economic situation and market needs.

1 INTRODUCTION

Emergencies cause great losses, both to the country's economy, to companies (enterprises), and to individuals. The means of avoiding emergencies are usually: means of preventing their occurrence, means of minimizing their consequences and insurance (which can also be partially attributed to the means of minimization). Nevertheless, insurance still stands aside from the means of minimization, since it has both the original and the initial result is cash. While the rest of the means of minimization is associated with the additional expenditure of material resources.

In the practice of the EU countries, North America, Southeast Asia and Australia, the majority of companies (enterprises) and individuals *insure their activities and property against the occurrence of emergencies*. However, in Ukraine, the share of financing measures to minimize the impact of emergencies through insurance payments made by specialized insurance companies is still slowly growing, despite the full-scale aggression of Russian Federation, and projects to be realized instead of. This is mostly due to the fact that protection from emergency situations of the population (individuals) by means of insurance is provided on a voluntary basis (Code of Civil Protection of Ukraine, 2013), and most Ukrainians avoid this (but legal entities (companies and enterprises) do it). Therefore, each person must decide for him on the need to insure his property (life, means of activity or health) in order to receive compensation for damages in the case of an emergency.

2 ANALYSIS OF THE PREVIOUS PUBLICATIONS

In many scientific publications (Bublik, 2009; Romanenko, 2007; Hargrave, 2022) and in practice, insurance is considered *as a means of minimizing the impact of natural and man-made emergencies*. According to Article 49 of the Code of Civil Protection of Ukraine (Code of Civil Protection of Ukraine, 2013) the purpose of civil protection insurance is:

1. property insurance of businesses and people against damages caused by an emergency, accident or emergency response operations;
2. insurance compensation on behalf of businesses operating high-risk facilities to third parties or their property and other legal entities for the damages caused by a potential emergency that occurred at such facilities.

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Regarding international level, the aspect of the international cooperation presented in (Dorussen et al., 2018; Barč et al., 2020). Assessing the capabilities of civil protection and preparing recommendations on how to implement these approaches presented in research of Kalynenko et al. (Kalynenko et al., 2020) only in 2020.

3 PROBLEM STATEMENT

Meanwhile, according to the above mentioned Code of Civil Protection of Ukraine (Code of Civil Protection of Ukraine, 2013) there are also *social and military emergencies*, which, namely, in Ukraine are most often considered as "*reasons of a force majeure essence", and therefore they are not the cause (reason) of the "insured event*".

But there is a problem regarding correct understanding categories for the correct insurance. As well as regarding correct implementation, especially nowadays.

The scientific novelty of the research is in formation of fundamentals for the disclosing and searching for the appropriate instruments of economic risks in Ukraine, for the possibility of effective management of emergent economy. It is due to the fact that "force majeure" has no one definition in modern Ukrainian legislation and it is the reason why such traditional instruments like insurance are not widely spread on the market of risks of economic emergencies, and this problem should be solved especially nowadays.

4 RESULTS

As there were mentioned above, the term "force majeure" was not officially enshrined in the legislation of Ukraine until recently, which gave rise to constant discussions about a clear interpretation of its definition (Sosnin, 2014). Thus, in the Civil Code of Ukraine, instead of the concept of "force majeure", which has a global perception, the concept of "force majeure circumstances"' appeared. In accordance with Art. 617 of the Civil Code of Ukraine, "A person who has violated an obligation is released from liability for violation of an obligation if he proves that this violation occurred as a result of an incident or force majeure. It is not considered a case, in particular, of non-compliance with its obligations by the counterparty of the debtor, lack of goods on the market necessary for the fulfillment of the obligation, lack of necessary funds from the debtor" (Tsyvilnyi kodeks Ukrainy, 2003). Art. 218 of the Commercial Code of Ukraine also provides a definition of "insuperable force" ("force-majeure"), and specifies a list of circumstances that are not related to force majeure: "A party to economic relations shall be liable for non-performance or improper performance of an economic obligation or violation of the regulations of economic activity, unless it proves that it has taken all measures to prevent an economic offence. Unless otherwise provided by law or agreement, for breach of economic obligation an economic entity shall bear economic and legal liability, unless it proves that proper performance of the obligation was impossible due to irresistible force, that is extraordinary circumstances beyond control under these conditions of economic activity. Breach of obligations by the offender's counterparties, deficiency of goods in the market required to fulfill the obligation, absence of required funds in a debtor shall not be classified as such circumstances" (Hospodarskyi kodeks Ukrainy, 2003). Thus, in their essence and the circumstances the appearance of the concept in both codes coincide.

However, the Supreme Economic Court of Ukraine in its one letter No. 01-2.2/279 of 09.09.2001 "Remarks to the Commercial Code of Ukraine" explained that the concepts of "force majeure" and "insuperable force" are not identical, since "the definition of the category of force majeure circumstances in part 2 of this article may cover not only events in public life, that is, the impossibility of fulfilling obligations as a result of targeted actions of persons who are outside the scope of the obligation (for example, embargo on export-import operations, hostilities, strikes, riots), but also natural phenomena that belong to a different category of circumstances that exempt from liability, namely insuperable force. Identifying these fundamentally different reasons for exemption from liability is legally wrong. The category of insuperable validity embodies only natural phenomena, which, due to their exclusivity, inevitability and unpredictability, determine the limitation of liability for damage in cases determined by law. Moreover, insuperable validity as a basis for limitation of liability can take place only in non-contractual (tort) legal relations and in cases of violation of contractual obligations, if it is directly provided for by law (for example, in cases provided for in Article 418 of the Commercial Code). At the same time, the category of force majeure covers only exceptional events of public life, which the parties themselves on dispositive grounds define in the contract as the right to exemption from further fulfillment of the obligation by agreement, if such events occur during the term of the contract. The parties may provide in the contract innocent liability

for non-fulfillment or improper fulfillment of obligations, but limit it to cases of force majeure provided for in the contract. Common to the circumstances of insuperable force and force majeure is only their external nature of influence on the causal-results chain of activity of participants in specific legal relations, that is, these circumstances are beyond the control of the participants in legal relations" (Supreme Economic Court of Ukraine, 2001). Consequently, *there was confusion about the interpretation of the terms "force majeure" and "insuperable force"*.

The concept of "force majeure circumstances (circumstances of insuperable force)", that is, already related to each other, was defined only in 2020 in the law, which is not directly related to this concept, – the Law of Ukraine "On Amendments to Certain Legislative Acts of Ukraine Aimed at Preventing the Emergence and Spread of Coronavirus Disease (COVID-19)" (COVID-19, 2020). Due to this law, amendments were made to the Law of Ukraine "On the Chambers of Commerce and Industry in Ukraine" (On Chambers of Commerce and Industry in Ukraine, 1998), by 1998. Since 2014, the law states that the Chamber of Commerce and Industry of Ukraine "confirms force majeure circumstances (circumstances of insuperable force) as well as trade and port customs adopted in Ukraine upon the request of business entities and natural persons; certifies force majeure circumstances in accordance with the terms and conditions of agreements upon the requests of business entities engaged in housing construction (customers, developers)". And from 17.03.2020, Art. 14-1 of this Law, defined: "Force majeure circumstances (force majeure circumstances) are the extraordinary and unavoidable circumstances that objectively unable to fulfil the obligations stipulated in the terms and conditions of the agreement (contract, treaty, etc.), obligations under the legislative and other regulatory acts, namely: the threat of war, armed conflict or a serious threat of such conflict, including but not limited to enemy attacks, blockades, military embargoes, actions of a foreign enemy, general military mobilisation, military actions, declared and undeclared war, actions of a public enemy, indignation, acts of terrorism, sabotage, piracy, riots, invasion, blockade, revolution, mutiny, insurrection, mass riots, curfew, quarantine established by the Cabinet of Ministers of Ukraine, expropriation, forced seizure, seizure of enterprises, requisition, public demonstration, blockade, strike, accident, illegal actions of third parties, fire, explosion, long breaks in transport operation, regulated by the terms of relevant decisions and acts of state authorities, the closure of sea straits, embargo, ban (restrictions) of export/import, etc. as well as caused by the exceptional weather conditions and natural disasters, namely: epidemic, strong storm, cyclone, hurricane, tornado, hurricane, flood, snow accumulation, ice, hail, frost, freezing of the sea, straits, ports, passes, earthquake, lightning, fire, drought, subsidence and landslide, other natural disasters, etc.".

In principle, such a definition has the power to stop all insurance activities in Ukraine, because it classifies *almost all insurance* incidents related to social, natural or man-made emergencies *as force majeure circumstances*.

In *international practice*, force majeure circumstances are determined in accordance with Article 79 of the UN Convention on Contracts for the International Sale of Goods (UN, 1980), according to which "A party shall not be liable for non-fulfillment of any of its obligations if it proves that it was caused by an obstacle beyond its control and that it was unreasonable to expect this obstacle to be taken into account when concluding a contract or to avoid or overcome this obstacle or its consequences".

In the international courts' practices regarding the definition of "force majeure" the question often depends on which system of law is applied – precedent (Anglo-American) or constitutional (Roman, continental). For example, "English law distinguishes between two main means of protection by a party that has committed non-performance of the contract due to *insuperable force*. These circumstances, although they result in the release of a party from liability, are fundamentally different from force majeure in that they are *non-contractual instruments*, while *force majeure* is introduced by the *contract*" (Kurylo, 2019). That is, no "non-contractual means of protection against liability for improper performance of the contract due to insuperable force under English law do not work if the parties include a force majeure clause in the contract".

Thus, insurance requires the most clear *definition of force majeure in insurance contracts* to develop a single consolidated position of the insurer, policyholder and reinsurer (if necessary).

Contra Anglo-American law *in the continental law, force majeure exempts from liability for improper performance of a contract only temporarily*: "French civil law, which follows Roman law, professes the principle of liability for violation of a contractual obligation in the presence of guilt (with certain exceptions). Reference to force majeure is not required if the non-fulfillment of the contract occurred in the absence of guilt on the part of the party to the contract that violated it" (Kurylo, 2019). That is, from the side of insurance companies, non-fulfillment of the contract becomes possible only for a certain pe-

riod of time, while the fault of the company itself is absent. *This actually makes it impossible to insure economic risks*, because when insuring funds against depreciation of inflation, the insurance company will not be to blame if it gives insurance payments with impaired funds.

Despite the confusion of the "force majeure" meaning in Ukraine, its definition in practice is simpler, which greatly simplifies its recognition in the insurance market. The regulations for certification by the Chamber of Commerce and Industry in Ukraine and by it's regional chambers of the force majeure circumstances (insuperable force circumstances) provide that in order to recognize and confirm force majeure circumstances (insuperable force circumstances), the documents provided by the applicant must indicate:

1) "the extraordinary nature of such circumstances (are exceptional and are beyond the influence of the parties);
2) unpredictability of circumstances (their occurrence and consequences could not be foreseen, in particular, at the time of the making of the relevant agreement, before the term of the obligation or before the occurrence of a tax duty);
3) inevitability (insuperability) of the circumstance (of the event and / or its consequences);
4) causal-results chain between the circumstance / event and the inability of the applicant to fulfill his specific obligations (according to the contract, agreement, law, regulation act, act of local governmental institutions, etc.)" (On Chambers of Commerce and Industry in Ukraine, 1998).

Thus, mentioned *legal conflicts significantly affect the sphere of insurance against emergencies*, since the sphere of liability, depending on the cause and consequences of the emergency, may differ significantly. Especially in specific types of emergencies.

In the publications (Trush and Gorovyi, 2018; Trush et al., 2019) another type of emergencies is defined depending on the cause of their occurrence – *economic emergency*: "As an emergency of economic character (economic emergency) can be considered a situation that is the result of erroneous economic actions of the government, the action of economic sanctions by other countries, hybrid hostilities, inflation, impoverishment of the population and loss of savings, unemployment and bankruptcy of enterprises and organizations, the exit of investors from the country, depreciation of the national currency and securities".

For this type of emergencies the principles of insurance are not currently used, but 'the signs' of such an emergency that cannot be used as force majeure conditions in accordance with the current legislation of Ukraine. Force majeure are social reasons that will cause a social emergency, which in turn will entail an economic emergency. And directly appearance of economic emergencies – namely, inflation (and for export-oriented countries, such as Japan, deflation), bankruptcy, unemployment, loss of savings (according to their purchasing power), exit of investors from the country, depreciation of the national currency and securities, – could be insured events, and are not considered as force majeure circumstances. At the same time, "war, hostilities, invasion of troops, insurrection, civil unrest, confiscation, forced seizure, requisition, seizure or damage to property by order of the government or other authority are not insurance events and *exclude compensation for possible damages under an insurance contract*" (Hroshi, 2022). But, in practice in Ukraine these terms of the contract apply only if martial law or a state of emergency is introduced in the country or in its part in accordance with the procedure described by the Law of Ukraine "On the Legal Status of the State of Emergency" (On the Legal Status of the State of Emergency, 2000). That is, "until the statement and entry into force of an official decision, insurers have no legal grounds to refer to such cases (even if in fact those actions that inherently agree with the above definitions take place)" (Trush and Gorovyi, 2018). Also, "attention should be paid to the fact that in almost all contracts of voluntary land transport insurance, in the section of the basements of refusing to pay insurance compensation, there is a pp. stating that hostilities, riots, acts of terror, civil unrest are direct basements for the insurer's refusal to pay insurance compensation" (Protsenko, 2016).

Thus, if the condition of the contract was precisely the insurance of certain economic emergencies, then the insurance company must compensate for the losses. At the same time, some of the economic emergencies are already included in the list of circumstances of unforeseen force. Consequently, in theory, you can insure against them in the insurance company, but the receipt of payments from it can be appealed, since they are included in the list of insuperable force. So, the '***circumstances of economic emergencies***' we divide into:

1. Can be insured:

1.1) erroneous economic actions of the government (however, it must be clearly stated in the contract what exactly should be considered as a wrong action);
1.2) inflation;
1.3) impoverishment of the population and loss of savings;

1.4) unemployment;

1.5) bankruptcy of enterprises and organizations;

1.6) depreciation of the national currency and securities;

1.7) exit of investors from the country (but must be clearly stated in the contract, what exactly is meant).

2. Included in the list of irresistible forces in Ukraine:

2.1) economic sanctions of other countries;

2.2) hybrid military operations.

Looking further, we should pay attention to inflation, its dynamics, and emergencies.

Deeply, the categories of 'cause' and 'effect' generalize one of the concrete and specific forms of relations, from a philosophical point of view. Thus, every event or group of events creates interacting phenomena; meanwhile, phenomena act for/regarding other reason. In its turn, the cause itself generates consequence. That creates a chain of causal relations between individual groups, defined "emergencies".

The economic impact of emergency is changing. At the same time, exactly the same problem could be solved as well during long time as immediately. From national example, the government did not stop quickly the sustainable growth rate of foreign currencies during 2014 in Ukraine, – and it had been already the period of war against Ukraine stared. Moreover, the opposite case: panic on the currency market at the end of December 2018 was resolved in a few days.

In general, the economic growths of emergency can be represented as it shown in figure 1.

As it can be seen, there are two main causes/reasons of the economic impact emergency depends on the "source" – external or internal. The consequences made on the base of (Pettinger, 2021), define the traditional causes of inflation, trade deficit, loss of savings (uncontrolled printing of money, currency devaluation, fiscal deficit, excessive taxation, monopolization of markets).

Consideration of the causes of significant fluctuations Ukrainian hryvnia in 2017-2018 years makes us identify another consequence of the economic emergencies – 'information invasion'. Huge changes ('jumps') of the hryvnia / US dollar and euro during the period are not fluctuating economic indicators of the state (GDP, index of production, consumer price index, etc.) or even obtaining or not of macrofinancial assistance from the IMF, the US, EU, etc. However, it coincides with the declared opposition protests and the spread of false information in the media by country-aggressor. Comparison the change of hryvnia / US dollar with information events in the country is presented on figure 2.

That is, the preparation and sharing in the media of an informational event (which may later lead to the onset of an economic emergency) still leads to significant fluctuations in the exchange rate and creates the ground for the economic emergencies.

For example, emergency from the reason of pandemic caused such changes of inflation in EU (figure 3) (Lane, 2021).

Related issues, namely in the context of shaping the sustainable development, were deeply researched by Ukrainian famous scientists (Semerikov et al., 2020). Risk assessment on the mesoeonomics levels (Pursky et al., 2021) are in the center of future researches as well, especially for after-war reconstruction of Ukraine.

Today in Ukraine, insurance services are provided by many insurance companies. As a rule, they offer a standard set of services for life insurance against accidents, health insurance (including tourist insurance), property insurance against emergencies, movable property insurance (including car owner's liability), insurance of agricultural producers against adverse weather conditions, medical insurance, etc. However, some insurance companies also offer specific types of insurance comparable to economic emergency insurance:

- credit limit insurance, flight cost compensation for the passenger, notary liability insurance, third party liability insurance (Credo, 2022);
- insurance of cases related to transportation: cargo insurance, forwarder and transport operator liability insurance, carrier liability insurance (PZU S.A., 2022);
- reimbursement of *cases related to cyber incidents, which caused stoppage of the production – cyber risks, the need to recover data* (INGO, 2022), etc.

However, quite rarely insurance companies agree with the voluntary payment of insurance compensation, taking into account inflation losses (avtopomich.com, 2016). Although earlier it was inflation that was the object of insurance. In the early 1990s, with the onset of Ukraine's independence and the rapid inflation of the old currency ('karbovantsy'), some insurance companies (for example, (Verbyanyi, 2012)), offered insurance of savings against depreciation caused by rapid inflation. Now there are no such offers on the Ukrainian market.

Another option of the 'lost' instrument of insurance of economic emergencies in Ukraine can be considered *insurance of non-repayment of bank loans*, which can be used as a guarantee of loan repayment

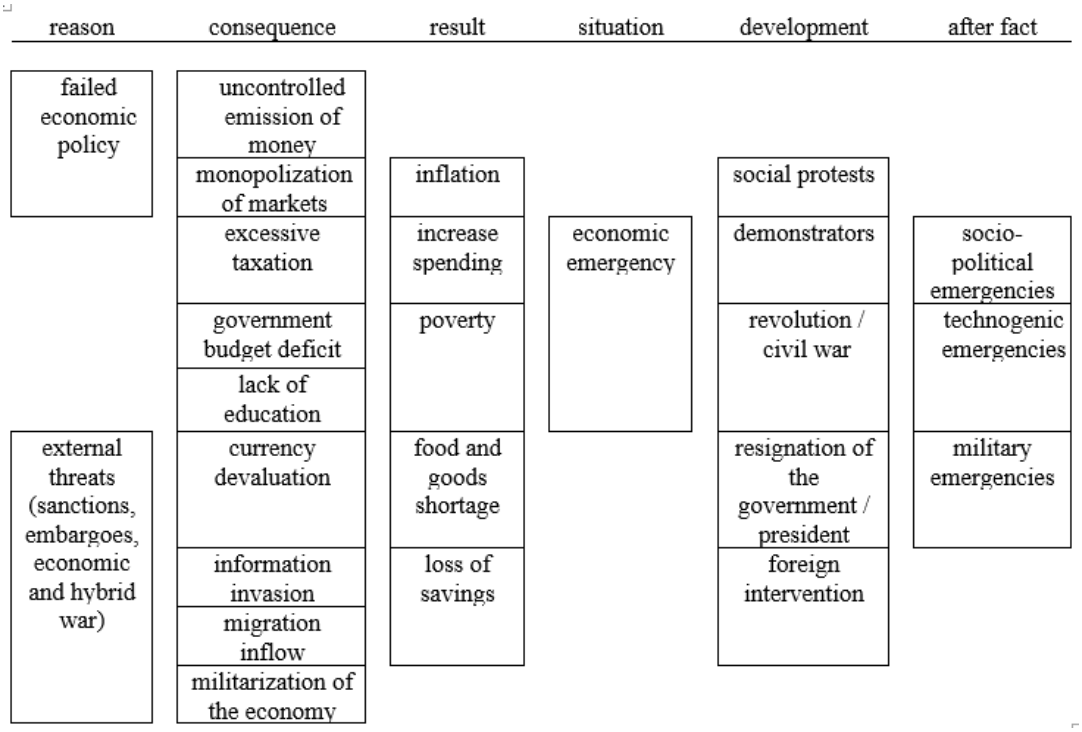

Figure 1: Scheme of emergency economic growths.

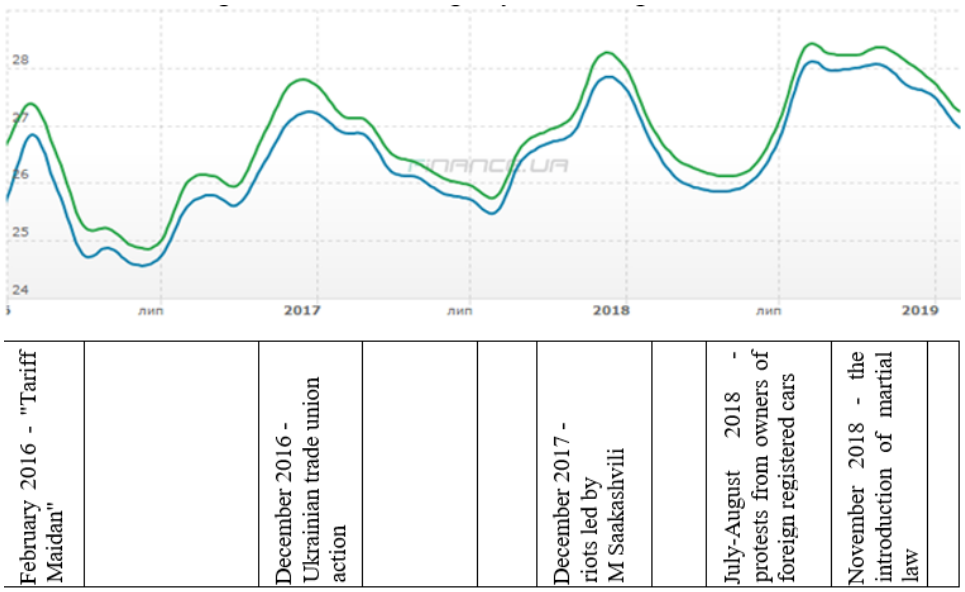

Figure 2: Comparison of change of hryvnia / US dollar with information events in Ukraine (charts.finance.ua, 2022).

(instead of a more common pledge of property or guarantees of third parties) (Katranzhy and Maryna, 2020). However, this form has not found its distribution due to a number of reasons (Chaykovskiy et al., 2001):

- "commercial banks cannot make extensive use of loan insurance today because they have well-founded doubts about the reliability and solvency of insurance companies, although there is an annual mandatory disclosure of balances;
- high insurance premiums demanded by insurance companies cause an increase in production costs due to insurance payments, which in turn leads to an increase in prices for goods and services;

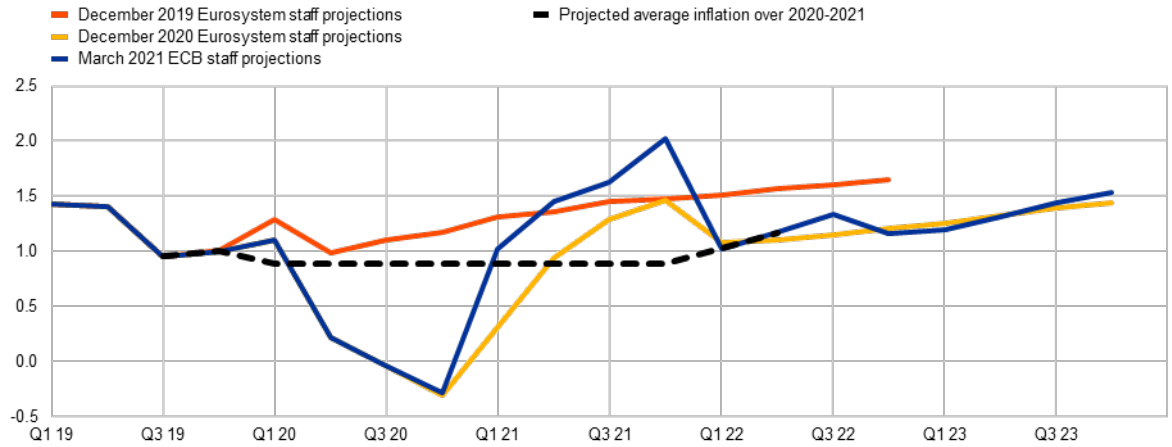

Figure 3: Selected (B)MPE projections for inflation.

- the procedure for issuing an insurance contract is complicated, which requires banks to work responsibly analytically to reconcile insurance rates, the nature of liability, and the transfer of insurance documents necessary for him to allow a regression claim against the borrower".

The interaction of commercial banks and insurance companies today is more common in the consumer market, where insurance companies reimburse the bank that provided the consumer loan funds in case of impossibility of returning funds by the borrower in case of damage or malfunction of the goods under which the loan was taken (Shchedryi, 2005).

We also appeal to insurance of projects' grant risks, as the last half of the year makes recipients think: to do them or not. For example, $\frac{2}{3}$ of socio-economical grants were on the way to give money back to grantholders. For example, we note what exactly written in grant agreements, namely by the British Council – "the party shall be released from responsibility for non-performance or improper performance of its obligations under agreement, if this non-performance or improper performance was caused by *unforeseen circumstances of force-majeure, occurred after execution of the Agreement due to emergency reasons, which could not be either forecasted or prevented by reasonable measures*. Such circumstances include events that are in spite of the parties' will, i.e. on which the parties have no influence and/or control and, therefore, for which they cannot be responsible. Such circumstances, inter alia, encompass natural calamities (for instance, earthquakes, inundation, flood, freezing, etc.), fires, other natural catastrophes and social cataclysm, strikes, *acts of terrorism, warfare, war*, etc. Such circumstances also include civil disorders, acts/inauspicious acts of government or other state bodies, blockade, embargo, other international sanctions, other negative acts of states, etc., which a respective party is not in connection with and which it has no influence upon. The party that is unable to perform obligations under this agreement shall within five calendar days notify the other party of the onset and cessation of force majeure. The presence and duration of force majeure is to be confirmed by the competent and assigned authorities in the manner prescribed by the applicable legislation in force. In the event of force majeure execution of the agreement shall be postponed for the time of duration of force majeure circumstances. If the force majeure lasts more than three months, either of the party may terminate this agreement in respect of the scope of outstanding services by serving the written notice". In contrast, in Ukrainian practice, according to the rules of insurance companies, "emergency states, special, or military emergences; civil disorders, revolutions, insurrections, uprisings, strikes, putsch, lockout, terrorist act; nuclear incident, exposure to ionizing radiation, radiation pollution; illegal actions of state bodies, local governments, officials of these bodies" basicly were called "exclusion from insured cases" (PZU S.A., 2022).

Regarding cases with insurance compensation the National Bank of Ukraine fixed 127 non-life insurance companies (01.09.2022). The total signed awards in the first half of 2022 compared to the first half of 2021 decreased by almost a third (-28%) and amounted to 17.8 billion. UAH. – at the same time, the reduction in volumes to a greater extent took place in the segment non-life (-29%); the volume of insurance payments/reimbursements paid in the first half of this year also fell proportionately in non-life segment (-32%). In the structure of the insurance portfolio, the volumes of insurance of property and fire risks (-60%), financial risks (-64%) and CASCO (-

30%) decreased the most. The drivers of non-life insurance business support were "Green Card" (+ 76%), MTPL (-13%), accident insurance (-16%). Insurance portfolio for the first half of 2022 by type of insurance presented in figure 4, and changes in activity volumes (21.03-04.09.2022), non-life, presented in figure 5 (National Bank of Ukraine, 2022).

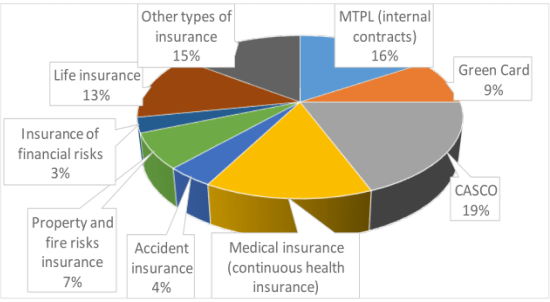

Figure 4: Insurance portfolio for the first half of 2022 by type of insurance in Ukraine (National Bank of Ukraine, 2022).

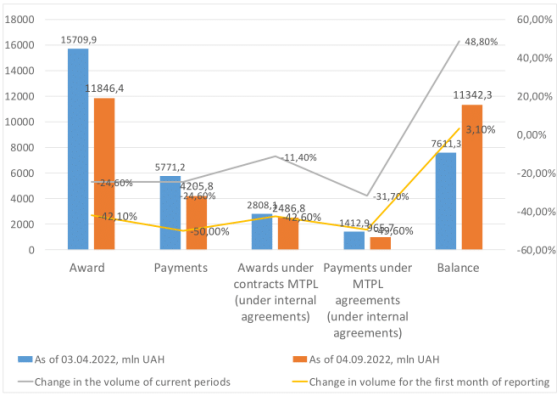

Figure 5: Changes in activity volumes (21.03-04.09.2022), non-life (National Bank of Ukraine, 2022).

The positive solutions for further development and for giving the most relevant results depend on possibility to change fast, to modernize organisation of all business-processes (Bogoyavlenska and Berezhnytskiy, 2020), being resilience to economic shocks (Bruneckienė et al., 2018). Moreover, new finances instruments, namely "innovation vouchers" developing too fast (Klímová and Žítek, 2020). In addition, according to American experts "by 2025, cyber insurance volume is expected to reach 15*to*20 billion. However, cyber liability insurance is a niche market, with risks that are largely underinsured. (...) The COVID-19 pandemic took a toll on the decades-long growth in merger and acquisition insurance. For instance, in the first quarter of 2020 alone, deal value and volume dropped by around 30%. Global premiums income shrank by 3.8% in 2020 due to the pandemic. In addition, property and casualty premiums went down by 2.9%. In a similar vein, life insurance premiums were down by 4.4%. According to the National Association of Insurance Commissioners, 83% of all business interruption policies have virus exclusions. Moreover, 98% of such policies include a property damage requirement. However, the question that remains is whether the virus itself can be equated to physical damage to property. This will likely be thrashed out in a lawsuit against the insurers and decided on a case-per-case basis." (Andre, 2022). In this way, and because the insurance industry is a growing sector, we are thinking of the necessity of creating new products for the insurance market (in hybrid military actions conditions it is very necessary).

5 CONCLUSIONS

Thus, partly due to the reasons and consequences of economic emergencies today in Ukraine in one form or another, it is possible to insure the risks associated with inflation, unemployment, impoverishment of the population and loss of savings, bankruptcy of enterprises and organizations, depreciation of the national currency and securities.

The circumstances of insuperable force (force majeure) are hybrid military actions and the application of economic sanctions by other countries.

And such reasons for economic emergencies as the withdrawal of investors from the country and the erroneous economic actions of the government have not yet been offered by anyone as an object of insurance. Therefore, they can be the direction of further research of both scientists and practitioners in order to find new insurance products.

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Economic Consequences of the War for Business in Ukraine: Analysis, Challenges, and Perspectives

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Keywords: War, Ukraine, Economic Impact, Business, Economic Entities, Exchange Rate, Export, Logistics, Migration, International Support, State Support.

Abstract: War is a complex social and economic phenomenon which causes tragedy due to irreparable human losses. Another implication of the war is a great damage to economy, which has its consequences in short-term, medium-term, and long-term perspectives. In order to overcome the war consequences, it is important to estimate, analyze and systematize the key impact for providing a comprehensive understanding of the state of the economy. The article contributes to such a holistic understanding as its purpose is to identify and to systemize the key economic consequences of the war in Ukraine. The authors systematized the key impact of the war for business in Ukraine according to the following spheres: business activity of economic entities, exchange rate, export, logistics, migration. It was defined that due to the scale of consequences and to the ongoing (at the moment of the article preparation) hostilities on the territory of Ukraine the state cannot overcome the damage on its own. This emphasizes the necessity of the international support. The key spheres of international support were examined according to the countries. The Ukraine state support programs were also revised in the article.

1 INTRODUCTION

Ukraine's economy has suffered from a range of issues for quite a long time. Political instability, incompletion of supply chains, high level of competition, vulnerability to the global crisis tendencies – all these factors form a significant impact on the conditions of Ukrainian economic entities functioning, thus, on the state of the economy as a whole. According to the calculations provided by Yakymchuk et al. (Yakymchuk et al., 2021) the level of economic security of Ukraine during 2009–2019 can be defined as crisis level. While fluctuating from year to year the corresponding level of economic security indicator has never reached a secure level. The following – 2020 – year has also brought severe shocks to the country's economy due to the COVID-19 outbreak. The year of 2021 was marked by some revival of business activity, but, at the same time, business entities and the economy as a whole did not have time enough to recover from the blow caused by the coronavirus pandemic. After the full-scale invasion of Russia the immediate result was GDP reduction by 40 % in the 2nd quarter of 2022, and the forecast inflation level is set as 31 % by the end of the year (National Bank of Ukraine, 2022a). Still, the medium-term and long-term consequences remain uncertain, as hostilities continue, the interaction of various factors causes effects of emergence and resonance, complicating the processes of forecasting and prediction. Therefore, we believe it is extremely expedient to provide research in the sphere of the war outcomes estimation in order to map out the ways out of the crisis and determine the key measures for the post-war reconstruction of the country. It should be mentioned that due to the complementary origin of the issue none of the researches can provide holistic understanding and comprehensive answers and solutions, but each research with its specific stressed points will contribute to the final result.

It is worth noting that the importance of study of the Russia-Ukraine war consequences is also determined by the role played by both countries in the world economy. For example, both countries mutually supply up to 25 % of world wheat export, and some of the countries (e.g., Armenia, Georgia, Turkey, etc.) import more than 75 % of the wheat consumed from Russia and Ukraine (World Bank, 2022). In addition to growing food insecurity risks, the war

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in the region has disrupted a lot of logistic channels, making it difficult, impossible and / or expensive to deliver goods internationally. While understanding the immediate consequences of the war, it is also important to analyze and forecast the medium and long-term impact in order to improve the effectiveness of the activities management and the post-war reconstruction of the country.

Thus, taking into account the importance of the outlined issues, as well as the fact that the determination of potential consequences for the economy of Ukraine is an important step on the way to the development of complex programs for overcoming the respective consequences, we believe that this study will contribute to the implementation of a comprehensive approach to the relevant range of problematic issues.

2 LITERATURE REVIEW

The Russia-Ukraine war has become a truly global conflict, as its implications form a great influence on most of the world's countries. Issues of dealing with such influence and overcoming the conflict consequences are of a special importance nowadays, that forms a significant scientific interest in the corresponding sphere of researchers all over the world.

The hostilities on Ukraine's territory have started in 2014, however, they didn't impact severely on the world's economy. Therefore, at that time, an insignificant number of publications were devoted to the consideration of issues related to the identification of the war's impact on economic relations. In particular, Garzon Gordon and Hierro Recio (Garzon Gordon and Hierro Recio, 2019) analyzed the impact of the war in Ukraine on global oil prices, taking into account the fact that Russia is a powerful player in the oil market. The study is devoted to determining the relationship between events in Ukraine and the price of oil. Bluszcz and Valente (Bluszcz and Valente, 2022) analyzed the costs of the hybrid war in Ukraine, considering the period of 1995–2017. The scientists defined that not only Ukraine, but also the neighboring countries suffer from the war consequences. The main indicator which is analyzed in the research is GDP per capita, and the authors state that Ukraine has lost about 15.1 % of GDP per capita due to the war in 2013–2017.

Russia's full-scale invasion of Ukraine in February 2022 had a significant economic, geopolitical, and social impact not only on the parties to the conflict, but also on other countries. This led both to the growth and scaling of the war consequences, and to the corresponding attempts to identify and predict the impact of the war on socio-economic relations. According to Astrov et al. (Astrov et al., 2022) the war has changed the world in many dimensions – military, economic, financial, and geopolitical. The comprehensive study is dedicated to estimating both immediate and medium-term implications of the war from the standpoint of three perspectives: implications for Ukraine, for Russia, and for the rest of Europe (Astrov et al., 2022). Orhan (Orhan, 2022) states that the consequences of the Russia-Ukraine war will affect not only the region, but also the economy on a global scale. The main spheres of impact include financial sanctions, increase of commodity prices, and supply chain disruptions. Glauben et al. (Glauben et al., 2022) analyze the implications of the war from the agricultural trade and food security standpoint. The authors define that Russia and Ukraine are both important market players regarding agricultural products and fertilizers, as their mutual market share was about 28 % for wheat, 15 % for corn, 66 % for sunflower oil, and 16 % for fertilizers. Thus, war consequences resulted in reduction of global supplies of mentioned products forming prerequisites for food security crisis in some countries and regions, especially countries from the MENA region. According to the estimations more than 300 million people are at critical high risk of food insecurity (Glauben et al., 2022).

One of the most discussed issues in current publications is related to migration trends, particularly refugees' flows. Thus, Duszczyk and Kaczmarczyk (Duszczyk and Kaczmarczyk, 2022) state that Poland has faced an unprecedented flow of refugees, which has created a lot of challenges for Poland as for the receiving country.

Prohorovs (Prohorovs, 2022) defines that the further consequences of the war should be examined within the following spheres: shocks of price, supplies, and supply chains; inflation; employment and unemployment rate; the economy growth perspectives; possible consequences of confrontation between the West and Russia. The research provides a comprehensive analysis of the war impact on the outlined spheres with a special stress put on the countries of the European Union. Markus (Markus, 2022) focuses on the business implications of the war for Russia. The implications for global business are also reviewed in the study. The researcher indicates the following consequences of the war: fuel global inflation, commodity shock, long-term fracturing of the global financial system. Korneyev et al. (Korneyev et al., 2022) have provided a detailed study of the war consequences for Ukraine. Particularly, the authors examine business activity reduction (with a focus on specific types of activity) and the governmental sup-

port programs, as well as they define the key challenges faced by Ukrainian business. The key challenges, according to Korneyev et al. (Korneyev et al., 2022) are as follows: supply chain disruption, shipping surcharge, consumer demand, creating stocks of products, the state of uncertainty among business representatives.

Despite the significant amount of research in this field, which makes a valuable contribution to creating a holistic understanding of the consequences of the war both for Ukraine and for the whole world, the outlined problem remains insufficiently covered in view of its complexity and multifacetedness. This determines the relevance of current research and determines its purpose and tasks.

3 OBJECTIVE OF THE RESEARCH

The purpose of the article is to identify and to systemize the key economic consequences of the war in Ukraine. The identification and systematizing of the implications will contribute to performing a holistic approach to the relevant issue, as well as they will serve as a basis for understanding the priority directions of action for overcoming the relevant consequences. The defined objective involves solving the following tasks: to identify key spheres of the war impact on business functioning in Ukraine; to analyze trends of changes in spheres selected for analysis; to systematize the main directions of international support of Ukraine; to consider existing governmental tools for overcoming crisis phenomena caused by the war.

4 METHODOLOGY

The methodological basis of the study is a system approach based on the understanding of socio-economic relations as a whole and, at the same time, structured system, which is subject to the catastrophic impact of military actions. During the research, the following methods were also used: monographic – when studying available publications and reports on assessing the consequences of the war; analysis and synthesis – to identify the key spheres of influence of the war consequences on the economy of Ukraine; generalization – for formulating research conclusions; ranking method – to determine the positions of individual countries in the overall ranking of aid to Ukraine; the deduction method – to determine the priority directions for the development of measures to overcome the consequences of the war; graphical and tabular – to visualize the obtained research results.

5 RESULTS OF THE RESEARCH

War is a complex socio-economic phenomenon that definitely affects all spheres of life, both in the countries participating in the conflict, and in the region or even the world. In addition to irreparable human losses, military actions also have a devastating effect on the economy, endangering the functioning of society. Wars can affect economic growth, the provision of production factors, the production structure, the public budget, and public debt (Garzon Gordon and Hierro Recio, 2019). Studying the consequences of war is an important component of developing programs for overcoming the respective consequences, because for the formation of adequate support programs, a clear understanding of the mechanisms of the impact of war on various spheres and aspects of the country's economic life is necessary. S. Mariotti states that the war is, on one hand, a result of growing global imbalances and instability and, on the other hand, is a cause of further growth of such instability (Mariotti, 2022). The globalization processes have led to a situation when regional conflicts (the Russia-Ukraine war particularly) affect a significant number of the world's countries, creating a negative impact on economic, social, and geopolitical spheres.

The war in Ukraine will have immediate consequences, as well as medium and long-term impact. Moreover, this impact will affect not only the counterparties of the war, but almost all countries of the world. The EU countries will suffer from inflation, price and supply chains shock, and likely will have to face recession or even stagflation (Prohorovs, 2022). The USA are not so vulnerable to the war consequences but will also fall under the impact of destructive tendencies created by the war (Prohorovs, 2022).

However, the biggest and worst impact will be on Ukraine. Since 2014 when the hostilities started at the Eastern Ukraine, the country has suffered from a considerable decline of economy (Bluszcz and Valente, 2022). The full-scaled invasion has led to much greater negative impact. The post-war reconstruction of Ukraine will require not only significant financial resources, but also a clear plan of action, like the Marshall Plan. In turn, the implementation of a comprehensive approach to the formation of an appropriate reconstruction plan requires a clear understanding of the main spheres of the war consequences.

The study of scientific literature, reports of

Ukrainian institutions and international organizations, as well as our own experience provided an opportunity to determine the key, in our opinion, spheres of the formation of the war negative impact on the economy of Ukraine. We consider it expedient to provide a description of the identified spheres.

5.1 Business Activity of Economic Entities

Full-scale military operations on the territory of Ukraine dealt an almost devastating blow to business, which has not yet fully recovered from the coronavirus crisis. Business entities faced a significant number of problems, starting from the physical threat to existence and the destruction of capacities in the areas of active hostilities and ending with the destruction of logistic channels and the reduction of solvent demand. Even if not situated in the active hostilities zone business entities experience all the consequences of the war: destabilization of the economy, disruption of supply chains, decrease in solvent demand, increase of inflation, etc. (Korneyev et al., 2022). It is worth noting that the extent to which business entities are affected can vary significantly depending on their field of activity. According to Korneyev et al. (Korneyev et al., 2022), the most vulnerable are the following spheres: agriculture, metallurgy, logistics, insurance. In particular, the NGO "The Institute for Economic Research and Policy Consulting" conducted a survey of representatives of domestic business in May-July to identify expectations and to assess the current situation. In July, 449 enterprises took part in the survey. Among them are mainly industrial enterprises located in 21 of the 27 regions of Ukraine, in particular in Vinnytsia, Volyn, Dnipropetrovsk, Zhytomyr, Zakarpattia, Zaporizhzhia, Ivano-Frankivsk, Kyiv, Kirovohrad, Lviv, Mykolaiv, Odesa, Poltava, Rivne, Sumy, Ternopil, Khmelnytskyi, Cherkasy, Chernivtsi and Chernihiv regions, and in the city of Kyiv (Kuziakiv et al., 2022). According to the results of the survey in July 2022, 31.9 % of respondents characterized the current financial and economic situation at the enterprise as bad, and the share of those who assess the situation positively was only 10.3 % (Kuziakiv et al., 2022). It is worth noting that such a share indicates the presence of significant crisis tendencies in the activities of enterprises, which, in turn, negatively affects the dynamics of general economic development indicators. According to the State Statistics Service of Ukraine, real GDP in the II quarter of 2022 decreased compared to the previous quarter by 19.1 % (taking into account the seasonal factor) and compared to the II quarter of 2021 – by 37.2 % (State Statistics Service of Ukraine, 2022). The key factors that create risks and threats to the existence of Ukrainian business entities include physical threats, exchange rate fluctuations, rising production costs, including due to rising fuel costs, disruption of logistic channels, problems with resource provision, including due to the emigration of the population, a decrease in solvent demand, etc.

5.2 Exchange Rate

One of the most significant spheres that has suffered a devastating impact as a result of military operations on the territory of Ukraine is the situation on the foreign exchange market. Significant shocks always have a negative impact on the exchange rate, the volatility of which increases significantly due to the uncertainty of the situation. In turn, changes in the exchange rate potentiate a significant number of further consequences related to the solvency of the population, inflation fluctuations, foreign trade policy, etc. Therefore, the exchange rate is one of the key indicators that has the property of emergence, that is, it affects a significant number of socio-economic parameters. It is worth noting that at the beginning of the full-scale war, in order to contain panic fluctuations and speculative risks, the National Bank of Ukraine (the NBU) fixed the official rate at UAH 29.25 per dollar (National Bank of Ukraine, 2022b). This measure was part of the set of actions introduced by the NBU to ensure reliable and stable functioning of the country's financial system. At the same time, the "retail" rate of the dollar differed significantly from the officially recorded one, which determined the need to use foreign exchange reserves to balance the market situation. According to official NBU data, gross international reserves during this period decreased from USD 29.087 billion equivalent (as of February 1, 2022) to USD 22.387 billion equivalent (as of August 1, 2022), i.e., by almost $6.7 billion or by 23.03 % (National Bank of Ukraine, 2022b). In order to preserve currency reserves, as well as to prevent the devaluation of the national currency, the NBU was forced to increase the discount rate from 10 % to 25 % in June. At the same time, this measure did not lead to stabilization of the currency market. In order to avoid further rapid reduction of foreign exchange reserves, on July 21, 2022, the NBU adjusted the exchange rate by 25 % to UAH 36.57 per dollar (National Bank of Ukraine, 2022b). It is worth noting that the official rate of the NBU can differ significantly from the market rate of commercial banks. This situation was especially critical in March-May 2022, when there was

a significant increase in the rate of commercial banks with the fixed rate of the NBU. The trend of changes in the exchange rate of the hryvnia to the dollar in commercial banks is shown in figure 1.

So, we can note a gradual, but significant decrease in the cash rate of the hryvnia to the dollar. Such a trend led to a significant number of negative consequences, including: a decrease in the solvency of the population, an increase in production costs, an increase in foreign debt in the hryvnia equivalent, as a result – a deterioration of macroeconomic indicators.

5.3 Export

One of the indicators of the socio-economic development of the country most significantly related to the hryvnia exchange rate is export. It is worth noting that, in general, the devaluation of the hryvnia has a stimulating effect on exports, but the military actions that led to the disruption of logistics chains (first of all, the blocking of ports) caused a significant reduction in exports.

According to the State Statistics Service of Ukraine (State Statistics Service of Ukraine, 2022), the export of goods in June 2022 amounted to 3177.5 million USD, and the value of exports for the corresponding period of 2021 was 5305.8 million USD, i.e., there was a decrease in exports by almost 40 %. The reduction in exports led to the formation of a significant negative foreign trade balance – (–1549.4) million USD. For comparison, the respective indicator for June 2021 was (–258.4) million USD. The following product groups experienced the greatest reduction: grain crops (exports in June 2022 were only 57.2 % of the level of June 2021); ready-made food products (50.9 %); mineral products (36.8 %); products of chemical and related industries (42.2 %); low-value metals and products from them (35.7 %) (State Statistics Service of Ukraine, 2022). One of the most crucial not only for Ukraine, but also for other countries (especially, of the MENA region) export products is wheat. As Glauben et al. (Glauben et al., 2022) state the most vulnerable are Albania, Egypt, Lebanon, Libya, Georgia, Mauritania, Sudan, Tunisia, and Yemen as large parts of their population are already subject to high risk of undernourishment.

The reduction in exports not only negatively affected the economic condition of exporting enterprises, a significant number of which faced serious difficulties with the sale of products and ensuring their existence, but also increased the devaluation of the national currency due to the reduction in the inflow of foreign exchange earnings to Ukraine. At the same time, a positive trend emerged. In June 2022 compared to May 2022 seasonally adjusted exports increased by 18.6 %, and imports by 27.6 %. Seasonally adjusted balance of foreign trade in June 2022 was negative and amounted to 1408.1 million USD. In May 2022, it was also negative – 889.9 million USD (State Statistics Service of Ukraine, 2022).

According to the official information of Ministry of Economy of Ukraine (Ministry of Economy of Ukraine, nd), in August 2022, the volume of Ukrainian exports increased by 25 % and amounted to 7.29 million tons. The increase in exports is connected with the partial unblocking of the ports of Greater Odesa. This made it possible to significantly increase the volume of export of Ukrainian goods. As a result, transportation by sea transport increased by 85 % and amounted to almost 2.9 million tons. Ukraine exported more than 3 million tons of goods by rail, 1.36 million tons by road. At the same time, exporters receive the largest revenue from goods exported by road – $ 1.48 billion, sea cargo – $ 995 million, and rail cargo – $ 788 million.

The leaders in terms of export value in August 2022 were (Ministry of Economy of Ukraine, nd):

- sunflower oil ($ 443 million). Its export volumes increased by 30 % to 366000 tons. Ukraine began to export less raw materials – sunflower seeds – and more processed products;
- corn ($ 347 million). Its export increased by 31 % to 1.5 million tons. It was this export segment that benefited the most from the unblocking of the ports from which ships loaded back in February left;
- rapeseed ($ 305 million). Ukraine has already exported 665000 tons of this crop of the new harvest;
- wheat ($ 213 million). In August, Ukraine exported 2.3 times more grain than in July, amounting to 880000 tons (Ministry of Economy of Ukraine, nd);
- ore ($ 172 million). As a result of the occupation and destruction of the south-eastern regions, the volume of exports of metallurgical products is decreasing. In particular, 1.4 million tons of ore were exported in August;
- cable products ($ 89 million). Despite the decrease in export volumes by 9.8 %, this category of goods remains one of the key ones;
- electricity ($ 73 million). Revenue from electricity increased by 2 times compared to July. This is the result of the successful integration of the Ukrainian energy industry into ENTSO-E – the energy system of the European Union;

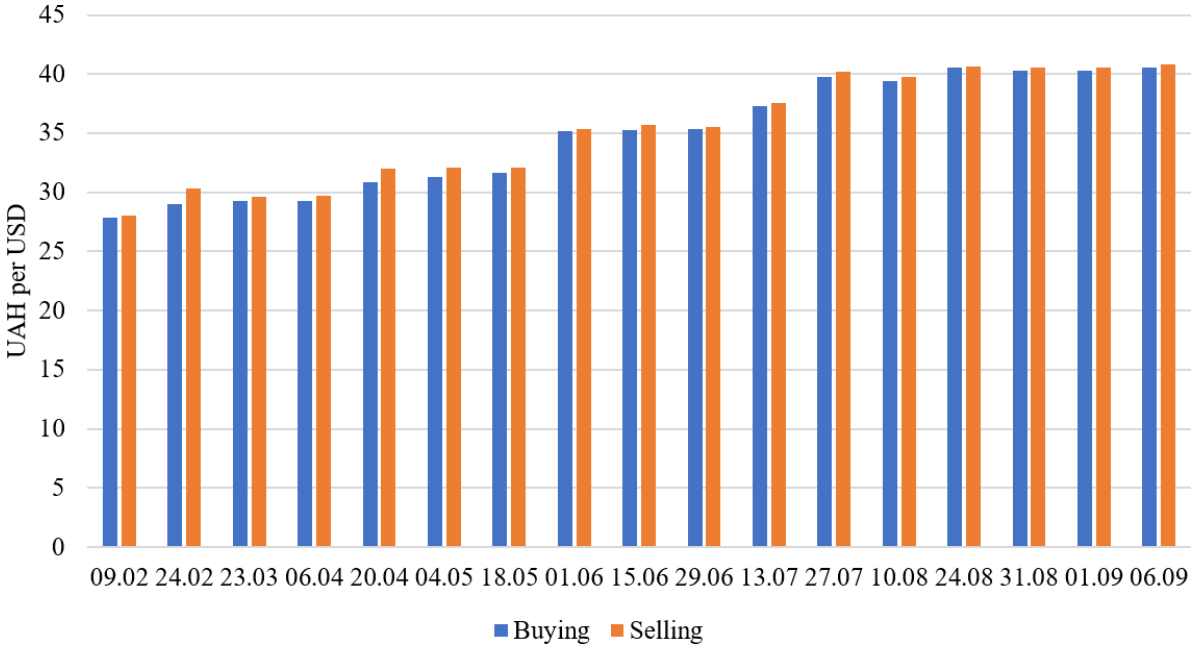

Figure 1: Dynamics of the weighted average exchange rate of the hryvnia to the dollar on the cash currency market of Ukraine (National Bank of Ukraine, 2022b).

- sunflower seeds ($ 71 million). Gradually, this segment of exports will decrease due to the growth of processing;
- poultry meat ($ 67 million). The export of products showed a decrease compared to July;
- soybeans ($ 62 million). In August, its export growth was +30 % to 148000 tons (Ministry of Economy of Ukraine, nd).

It is important that confectionery processing products show stable upward dynamics: bakery +19.4 %, sugar +9.1 %, chocolate +25 % (Ministry of Economy of Ukraine, nd).

We have optimistic prediction from the First Deputy Prime Minister, Minister of Economy of Ukraine Yulia Svyrydenko (Shalal, 2022). She told Reuters that Ukraine's economy should stabilize over the coming year and expand by as much as 15.5 % in 2023, depending on military actions development in the war against Russia that began on February.

5.4 Logistics

The well-adjusted transport and logistics activities of the country are determined not only by the direct restoration of the national economy but also by the preservation and further development of international relations, which are of key importance for modern economies of developed countries (Ohar et al., 2022).

During the war, the traffic flow increased. Since the beginning of the war, the seaports have remained virtually blocked, so the main part of trade flows has been taken over by road and rail transport. Today roads and transport points are usually the most damaged and destroyed as strategically important objects for the movement and storage of military equipment and, consequently, as battlefields. As of May 2022, as a result of hostilities on the territory of Ukraine, about 23 % of railway tracks were damaged, including 6.3 thousand km of main tracks. In the first quarter of 2022 exports amounted to 102.9 % compared to the first quarter of 2021, imports – 94.4 % compared to the same period last year. At the same time, foreign trade operations were conducted with partners from 214 countries (Ohar et al., 2022). We must also emphasize the breaking of chains, the destruction of transport routes, the exclusion from operation of key trunk roads that connected the West, Center, and East (the Lviv-Kyiv and Kyiv-Kharkiv route); fuel shortage and high fuel prices; frequent air alarms; highway logistics stopped working at night due to curfews and difficulties at roadblocks.

In general, it is worth noting that the war and its consequences from the point of view of logistics and infrastructure determined the understanding that in the future, when rebuilding the state, localization and the creation of alternative infrastructure are necessary (Markus, 2022).

5.5 Migration

Another painful issue for Ukraine as a whole, and for the economy in particular, is population migration related to hostilities. Orhan (Orhan, 2022) states that the most significant consequence of the war between Russia and Ukraine is the lives lost and the humanitarian crisis associated with the large number of people besieged and displaced. A great number of people left the country (this trend was especially significant at the beginning of the war), in addition, many people were forced to move within the country (internal displacement). Such a situation has significant negative consequences for the business activity of economic entities, because the decrease in the number of the population located on the territory of Ukraine has led to both a reduction in demand (due to a decrease in the number of potential consumers) and to problems with staffing of economic entities. Approximately 2.75 million refugees from Ukraine are of working age, of whom 1.2 million worked before the start of the war in Ukraine and, accordingly, could enter the EU labor market (Prohorovs, 2022). This situation results in the absence of the respective human resources in Ukraine and complicates business entities functioning. This was especially clearly visible in February-March, when enterprises and organizations could not always adjust their work due to the lack of employees (for example, pharmacies belonging to critical infrastructure suffered from the lack of pharmacists who could work, which, in turn, determined reduction of pharmacy networks even in relatively "calm" regions).

According to the Office of the United Nations High Commissioner for Refugees (UNHCR, 2022), as of September 7, 2022, 7.16 million refugees from Ukraine were registered in Europe. The largest number of refugees is registered in Poland (1.37 million people), Germany (1 million people), and the Czech Republic (0.43 million people). In total, since the beginning of the war, according to the UNCHR, 11.9 million people crossed the borders with European countries towards Europe and 5.3 million people moved towards Ukraine. In addition, according to the estimation, almost 7 million people are internally displaced within Ukraine. These trends cause problems with providing shelter for a significant number of displaced persons (UNHCR, 2022). The closest countries – Poland and Romania – faced a situation of unpreparedness for such a large number of refugees, a similar situation is observed in Ukraine in the western regions. As Astrov et al. (Astrov et al., 2022) define "For example, the population of Lviv – the largest city in western Ukraine – is only about a quarter of the size of Kyiv.... It is a logistical nightmare to find accommodation for half of Kyiv's population (or about 1.5 m people)". However, Poland is playing the most important role in providing sanctuary for Ukrainian refugees. This phenomenon is caused by several reasons. First of all, Poland is a bordering country which is situated in the west, this creates a more or less safe route for fleeing. Secondly, there is a long-lasting tradition of labor migration from Ukraine to Poland, which started long before the full-scale war started (Duszczyk and Kaczmarczyk, 2022). Such tradition made it easier to find shelter, to build logistics, etc.

5.6 Measures for Overcoming Negative Consequences

The spheres of the negative consequences of the war discussed above are not exclusive and exhaustive, because the large-scale military actions on the territory of Ukraine had an extremely negative impact on all spheres of socio-economic life. Destruction of infrastructure, reduction of business activity, decline in GDP, significant increase in inflation, population migration are just some of the challenges that Ukraine has faced. Overcoming the consequences of such challenges requires significant efforts, coordination and, first of all, financial resources. Suffering from military operations, Ukraine is currently unable to independently overcome existing and projected problems, that actualizes the need and determines the importance of international assistance. In the next section of the article, we find it expedient to consider the specifics of providing international aid to Ukraine as well as governmental aid to business.

5.7 International Support

Under the war conditions, when the situation changes every day, it is quite difficult to predict the consequences of Russia's aggression both for Ukraine and for the world. Faced with the incredible desire of Ukrainians to protect the country's sovereignty and fight back against the enemy, foreign partners provide comprehensive assistance to Ukraine. Starting from February 24, partner countries are helping Ukraine in various ways.

We analyzed the amount of aid from foreign partners and summarized the open sources of two platforms – Ukrainian FORBES (Landa, 2022) and The Kiel Institute for the World Economy (Antezza et al., 2022b). Poland, Estonia, Latvia, United States, and Lithuania took the first places in the updated rating of "Friends of Ukraine" from FORBES. In general, the authors have presented a rating for twenty countries, including sixteen European countries. In the "Friends

of Ukraine" rating (7) the authors have considered the following indicators (Landa, 2022):

- voting at the United Nations General Assembly for the withdrawal of Russian troops, the introduction of sanctions against Russia and the closure of its airspace, participation in the conference to support Ukraine on the basis of "Ramstein Air Base", the inclusion of Russia in the list of hostile countries I(1),
- the recognition of the genocide of Russia/USSR against Ukraine I(2),
- the expulsion of Russian diplomats I(3),
- the amount of aid to Ukraine, according to the Kiel Institute, in monetary terms, € billion I(4) and as % of GDP I(5),
- visits of high-ranking officials to Ukraine I(6).

In table 1 we have described the TOP-10 countries in the "Friends of Ukraine" rating.

Forbes has determined the financial component of the "Friends of Ukraine" rating based on the information from The Kiel Institute for the World Economy. The Kiel Institute for the World Economy focuses only on government-to-government transfers to Ukraine (Antezza et al., 2022b). The Ukraine Support Tracker lists and quantifies military, financial, and humanitarian aid promised by governments to Ukraine between January 24, 2022, and currently through August 3, 2022. It covers 40 countries, specifically the EU member states, other members of the G7, as well as Australia, South Korea, Turkey, Norway, New Zealand, Switzerland, China, Taiwan, and India.

We have summarized the data of the Institute's report (Antezza et al., 2022a) of various types of assistance to Ukraine. Some institutions are closed, and it is very difficult to find reporting information on them (such as the United Nations or the Red Cross). Support from major international organizations includes:

1. IMF programs: On March 9, the International Monetary Fund announced and disbursed an emergency assistance loan of $ 1.4 billion to Ukraine under the umbrella of its Rapid Financing Instrument.
2. The World Bank: According to the data provided by the Ministry of Finance of Ukraine, out of the $ 2.467 billion $ 929 million have been disbursed so far, a share of 37.66 %.
3. The European Bank for Reconstruction and Development (EBRD): On March 9 an international organization half-owned by European countries, announced a support package for Ukraine and neighboring countries totaling $ 2 billion.

Total aid to Ukraine is €84.2 billion (from European Union and 40 countries from January 24, 2022, until August 3, 2022). In table 2 we compare the type of government support to Ukraine by type of aid: military, humanitarian, and financial directions (TOP-10 countries in billion Euros).

Table 2 shows that The United States government alone (€44.5 billion) committed almost four times as much to Ukraine than all the individual EU country governments combined (€16.22 billion). However, the large commitments by the EU institutions bring the total European support to a level closer to the US. The United States clearly remains the largest donor to Ukraine.

Table 3 shows the amount of aid provided to Ukraine by other countries compared to the GDP indicator. Considering the GDP indicator provides an opportunity to determine the contribution of each country taking into account the level of economic development of the respective state.

Table 3 shows that Eastern European countries stand out as particularly generous when considering the size of their economy, with Estonia, Latvia, Poland, and Lithuania ranging among the top ten donors. The United States (being the largest donor in absolute terms) comes in 10th, with assistance worth around 0.22 percent of its GDP. Also, Eastern European countries show even higher commitments relative to GDP if one were to account for support by hosting Ukrainian refugees.

5.8 Ukrainian State Support for Business During the War

Supporting Ukrainian businesses is an important task to ensure the economic capacity of Ukraine to meet the challenges of war. Revitalization of the entrepreneurial activity is a key factor to enhance the country's stability and to overcome the consequences of the war (Korneyev et al., 2022). The state is taking affordable steps to support companies that find themselves in difficult conditions. In table 4 we have summarized the main state initiatives to support business in wartime, presented on the "Diia. Business" government services portal.

The effectiveness of government initiatives is varying. For example, according to the information from The Ministry of Economy of Ukraine (Ministry of Economy of Ukraine, nd), at the end of August, 725 enterprises moved from the regions of active hostilities to safer ones, of which 528 have already resumed their activities at the new location. Another 284 companies are currently searching for a suitable location or method of transportation. Among the relo-

Table 1: Top-10 countries in the "Friends of Ukraine" rating (Landa, 2022).

Country	Indicators						Rating (7)
	I(1)	I(2)	I(3)	I(4)	I(5)	I(6)	
Poland	Yes	Yes	45	5.1	0.88	President, Prime minister	100
Estonia	Yes	Yes	17	0.3	1.13	President	96
Latvia	Yes	Yes	16	0.3	1.03	President	96
United States	Yes	Yes	12	44.5	0.22	House speaker, Secretary of State	93
Lithuania	Yes	Yes	5	0.3	0.55	President	90
Portugal	Yes	Yes	10	0.5	0.24	Prime minister	90
United Kingdom	Yes	Partly	23	6.6	0.25	Prime minister	89
Italy	Yes	Partly	30	2.8	0.15	Prime minister	89
Spain	Yes	Partly	25	2.3	0.19	Prime minister	88
Slovakia	Yes	Partly	38	0.4	0.43	President, Prime minister	88

Table 2: Government support to Ukraine: type of aid, € billion (Antezza et al., 2022b).

Country	Type of aid, € billion			Total, € billion
	military	financial	humanitarian	
United States	25.0	9.2	10.3	44.5
EU Institutions	2.5	1.42	12.3	16.22
United Kingdom	4.0	0.38	2.10	6.48
Germany	1.2	0.75	1.15	3.1
Canada	0.96	0.26	1.82	3.04
Poland	1.80	0.10	0.99	2.89
France	0.23	0.12	0.80	1.15
Norway	0.21	0	1.03	1.24
Japan	0	0	0.59	0.59
Italy	0.15	0	0.31	0.46

Table 3: Government support to Ukraine: by donor GDP, incl. refugee costs (Antezza et al., 2022b).

Country	Bilateral aid (percent of GDP)	Refugee costs (percent of GDP, rough baseline estimate)
Estonia	0.8	0.4
Latvia	0.8	0.3
Poland	0.5	0.5
Czech Republic	0.2	0.4
Lithuania	0.3	0.3
Slovakia	0.2	0.2
Norway	0.4	0.02
Bulgaria	0.01	0.31
United Kingdom	0.2	0.01
United States	0.22	0.00

cated enterprises that have already resumed their activities in the new place, the largest part is formed up by enterprises operating in the sphere of wholesale and retail trade – more than 40 % (of the total number of relocated enterprises) and enterprises in the sphere of processing industry – 30 %. Also, among displaced companies, almost 7 % are active in the sphere of information and telecommunications, 6 % – in professional, scientific and technical activities, and 4 % – in the sphere of construction. The most significant number of enterprises were relocated to Lviv (29 % of relocated enterprises), Zakarpattia (18 %), Chernivtsi (13 %), Ternopil (8 %) and Khmelnytskyi (7.6 %) regions. Among the large companies that were relocated are LLC "Pozhmashina", LLC "CORUM Druzhkovka Machine-Building Plant", LLC "Staleks", PJSC "Kramatorsk Heavy Duty Machine Tool Building Plant" (Ministry of Economy of Ukraine, nd).

Another important direction of state support for business is preferential taxation, which made it possible to reduce the tax burden for enterprises and thus mobilize additional reserves to ensure the survival of business entities.

Based on open sources, we have summarized the tax innovations information proposed by the government:

1) individual entrepreneurs of the I and II groups (simplified tax system) during the martial law and within a year after its completion will be exempted from paying a single social contribution;

Table 4: Spheres of state support for business during wartime (Diia.Business, 2022).

Sphere	Explanation
Compensation for employment of internally displaced persons (IDP) or 6,500 hryvnias within eSupport	Compensation to the employer for labour costs for each internally displaced person. The source is the state budget reserve fund. Ukrainians will be able to receive UAH 6500 within the eSupport program in the areas where the most active hostilities are taking place. These funds can be used to pay for any expenses without restricting the type of business. Hired employees and individual entrepreneurs of all groups will be able to receive assistance.
The Government program of the enterprises evacuation from the combat zone	The government has presented the program for the evacuation of enterprises from the war zone to the west of Ukraine. Businesses will be provided with appropriate conditions for work in the new place and employment opportunities for people. Enterprises will be provided with assistance in selecting locations for their production facilities, transportation and resettlement of personnel, and search for new employees. The program is aimed at preserving the production and labour potential of Ukraine and is aimed at all enterprises that wish to move production to the territory of the western regions of Ukraine.
The Government program "eWork"	Any Ukrainian who does not work at other enterprises can take part. To receive money, you need to submit an application through "Diia" or in the branches of the OshchadBank together with the attached business plan. Money can be received by anyone who has the desire, skills and plan to start their own business or expand their business. For the grant, it will be possible to purchase equipment, buy raw materials or pay for the rent of the premises. For example: – Grant for own business: up to UAH 250000 – Gardening grant: up to UAH 400000 – Greenhouse grant: up to UAH 7 million – Grant for a processing enterprise: up to UAH 8 million.
State support "Credit program for exporters"	Credit program for companies that, due to the aggression of the Russian Federation, need additional financing for the implementation of export contracts. The affordable financing program for exporters during the war "Loans for the implementation of foreign economic contracts under a simplified procedure" will help Ukrainian manufacturers enter new markets and become competitive.
Support of Ukrainian entrepreneurs under conditions of war to preserve business and jobs	The tool from the UA Anti-crisis initiative will help to gather information about resources, build a strategy and take specific steps to start a business with the aim of faster recovery of the Ukrainian economy.

2) enterprises and individual entrepreneurs of the III group (simplified tax system) will be exempted from paying a single social contribution for employees who joined the armed forces and other armed groups (including territorial defense). The fee will be paid by the state;
3) payment of taxes for all enterprises that are unable to pay them is postponed;
4) the introduction of cash registers for all individual entrepreneurs is postponed;
5) all measures of the market and consumer surveillance in all matters, except for price regulation and control over pricing, will be abolished. A moratorium on inspections of all types for business has already been established.

Tax innovations also involve the following measure: VAT and income tax have been replaced during the wartime by a 2 % turnover tax (the transition to this taxation system is voluntary). The taxation of fuel is also diminished in order to constrain the prices (Astrov et al., 2022).

Summarizing the above mentioned, we can conclude that currently a significant number of measures to overcome the consequences of the war in Ukraine are already being implemented by both foreign governments and the government of Ukraine. However, we should note that most of these measures are aimed at ensuring business survival and ongoing support for Ukraine, while spheres related to the post-war reconstruction of the state are also important. We see the prospects for further research in the formation of a complex system of measures for overcoming the negative consequences of the war in Ukraine.

6 CONCLUSIONS

War in Ukraine is a powerful trigger, significantly increasing the level of inflation and exacerbating the existing issues of economies. Companies and countries have needed to adapt their activities to the consequences of the Russian war in Ukraine. The consequences of the war for Ukraine are especially significant (for objective reasons), because currently Ukraine suffers not only from direct military actions, but also from the economic consequences associated with them. Therefore, it is extremely important to understand the consequences of the war both in the short-term and in the medium-term perspective. The article identified the key directions of the formation of the negative impact of the war on socio-economic relations in Ukraine. It is worth noting that business in Ukraine faced unprecedented challenges related to both the threat to existence (physical) and the destruction of economic ties, the loss of sales markets, the increase in costs, and the decrease in the efficiency of functioning. Based on the results of the research, the main risks and threats were systematized in the following spheres: business activity of economic entities, exchange rate, export, logistics, population migration (refugees). The researched list of directions of the formation of the war negative impact on socio-economic relations in Ukraine is not exhaustive, but it provides an opportunity to contribute to the formation of a holistic understanding of the state and prospects for the development of the situation in Ukraine. In turn, such a comprehensive understanding will serve as a basis for developing complex programs to overcome the negative consequences of the war in Ukraine. Based on the analysis of the scale of negative consequences, it was determined that, given the current situation, Ukraine is unable to independently overcome the existing problems, which determines the importance of international support. Currently international support should be analyzed in two directions: diplomatic and financial (in terms of military, humanitarian, and purely financial). The largest contribution to total aid in absolute terms was made by the USA, however, if the analysis is carried out in comparison with the GDP of the respective country, then the countries of Eastern Europe (Estonia, Latvia, and Poland) take the first places in terms of aid. At the same time, the government of Ukraine implements measures aimed at supporting both business and the population, which is extremely important from the point of view of preserving the country's potential. We see the prospects for further research in the formation of a complex system of measures aimed at overcoming the consequences of the war in Ukraine, which will be based on the data of the econometric model for assessing the impact of individual factors on the resulting indicator (for example, GDP).

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Institutional Economics in the Face of Global Challenges in Europe

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Abstract: The reflections undertaken, according to their authors, are an attempt to use the scientific achievements of the new institutional economics to identify, analyze and evaluate global challenges for the European community. They are an intellectual response to the development dilemmas of the contemporary world, which arouse the interest of representatives of all contemporary currents of economic thought and practice. For the authors of the article, the need and advisability of approximating and linking these two layers has also become an area of research aimed at documenting the usefulness of an institutional approach to the study of complex problems of the contemporary world – with emphasis on those concerning the European continent. With such expectations in mind, the considerations were firstly focused on identifying the achievements of institutional economics as an inspiration for solving the challenges of the contemporary world. In the second instance, the main focus is on identifying, analyzing and assessing the challenges facing the European community in relation to human, material and relational resources.

1 INTRODUCTION

The development challenges of the modern world arouse the interest of many sciences – including all contemporary currents of economic thought – and prompt their representatives to address them. Their persistence and even deepening proves the ineffectiveness of generalizations of these problems by the leading currents of classical economic thought. This is the case when the practice of socio-economic life forces the search for effective hints for their solution. This is the case when a set of challenge planes is expanding, namely: political-military, social and economic, natural-climate and ecological, technical-technological, health, and cultural and civilizational (Camdessus, 2019; Dziurny, 2020; Friedman, 2009; Landes, 2015; Pobłocki, 2020; Randers et al., 2014; Stachowiak, 2004).

Many of the numerous development perturbations of the modern world affecting changes in economic activity and the well-being and prosperity of the global community were recognized and identified in the Millennium Development Goals of the UN Millennium Project - adopted at the UN Session in 2000 (Ośrodek Informacji ONZ w Warszawie, 2022) – and the 2030 Agenda for Sustainable Development – adopted by the UN in 2015 (OECD, 2017). These perturbations have also affected the European community, becoming the premise for the formulation of challenges to be addressed as a responsibility of the entire European community.

Their solution rests with a whole range of scientific disciplines, which are expected to develop theoretical generalizations as well as practical directives for their solution. One of these scientific disciplines is institutional economics – which in its contemporary perception is referred to as new institutional economics. Its theoretical output, built on an interdisciplinary approach to solving social and economic

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problems, can become a source of inspiration for solving the challenges facing the European community (Borkowska et al., 2019; Stanek, 2017; Stankiewicz, 2014).

2 INSTITUTIONAL ECONOMICS AS AN INSPIRATION FOR SOLVING THE CHALLENGES OF THE MODERN WORLD

The logic of thinking reflected in the views of institutionalists, especially those representing the 'new' (as opposed to traditional) institutional economics, is based on a paradigm referring to the scientific work of leading neo-institutionalists. It refers to the traditional views of this current and the concepts used by them, among which the category of "social institutions" should be identified as the leading one understood as dominant ways of thinking that take into account social conditions, the functions of the individual and the community, as well as habits of thought and ways of apprehending phenomena by which people are guided. Because they are products of the past, adapted to new conditions, they are therefore never in complete harmony with the requirements of the present (T. B. Veblen[1]). The source of their transformation is to be found in the constant improvement of technology (Veblen, 2008).

At the same time, institutionalists were aware – in addition to the premises that determined the need to articulate the paradigm of the new institutional economics – of the demands placed on it, namely that: it is not given once and for all – but should be adopted by consensus of the majority of researchers. They assumed that it could periodically undergo fundamental changes leading to profound changes in science associated with the scientific revolution. They also assumed that it should be characterized by: logical and conceptual coherence; relative simplicity, i.e., it should contain only those concepts and theories that are genuinely necessary for the science in question; and allow for the creation of detailed theories consistent with known facts. This was followed by the formulation of several fundamental questions, namely: is reality objective or partly subjective? does one have to be a participant in a social process in order to understand it well? and, does social reality undergo constant change or is it still the same? The answers to all of these questions provide a substrate for the identification and solution of Europe's global and regional development problems.

Useful for addressing the challenges of the modern world – according to the authors of the article – is the fact that the institutionalists enriched the picture of the process of socio-economic development with the setting of 'culture', which they saw as an organized system of human behavior in which there is an institutional (also called ceremonial) area on the one hand and a technological area on the other (Stankiewicz, 2014). In their view, any economic system remains under constant pressure, on the one hand from the forces of various institutions (legends, customs, social hierarchies) and on the other hand from the incentives generated by technology (C. E. Ayres[2]).

Institutionalists, referring to the instrumental philosophy dealing with the use of limited resources to achieve individual and group goals, formulate the postulate of adaptation of these opposing forces. The area of this process is the economic system, which is formed by two interrelated but contradictory blocks: the first is the block of the price economy identified as a complex of historically shaped institutions adopting ceremonial behavior, whose value derives from power based on the power of money; the second is the block of the industrial economy based on technology, science and the proliferation of labor tools. Each generates different values, the first price value and the second industrial value. Their synthesis is the idea of a rational society, whose determinants should be abundance of goods, quality of life, freedom, security and excellence. The progress of society, understood in this way, should be aimed at, that is, the progress that ensures the continuity of humanity through the development of science and creativity, rather than the progress that pursues the goals of maximizing utility and satisfaction resulting from the aspirations of individuals. The correct direction of its evolution should be supervised by the institution of social planning.

Views formulated on the basis of an analysis of the disintegration of 19th century civilization characterized by: balance of power, gold standard, self-regulating market and liberal state (K. Polanyi[3]), supported by arguments from economic anthropology,

[1]Thorsten Bunde Veblen (1857-1929) – American of Norwegian origin, sociologist and economist, master of the entire institutional stream. Author of "The Theory of the Leisure Class" (1899).

[2]Clarence Edwin Ayres (1891-1972) – American, professor of economics and philosophy, representative of one of the most important centers of evolutionary economics (University of Texas at Austin). Author of many publications, including: "The Theory of Economic Progress" (1944) and "Toward a Reasonable Society" (1962).

[3]Karl Polanyi (1886-1964) – Austrian, lecturer at the universities of Oxford and London. The author of the work "The Great Transformation; The Political and Economic Origins of Our Time" (1944).

should be considered useful and valuable, for the investigations undertaken. They proved that this civilization collapsed because its economy was based on self-interest and worked against the interests of society (Stankiewicz, 2014).

Necessary for deliberations aimed at identifying the challenges facing Europe and developing directives for solving them is to take into account the methodological achievements of the representatives of this current (I. Lakatos[4]), who, despite their oftendiametrical differences (K. R. Poper[5], T. S. Kuhn[6]), tried to bridge the gap between them. On the one hand, the research procedure leading to a theory from making a lot of observations and using inductive reasoning (K. R. Poper) was rejected, postulating a research path according to the scheme: posing a certain problem by the existing theory – eliminating the errors of the old theory – posing a new problem. In this connection, historicism was also fought against as a view of being able to predict the inevitable course of history. On the other hand, historical knowledge was assigned an important role (T. S. Kuhn), believing that it should not be regarded merely as a repository of chronological descriptions of events, which seek to reconstruct a continuous line of development, but as a detection of the integrity of science in particular periods. This was followed by the introduction as a particular "matrix of scientific discipline", which was understood as a set of certain generalizations, models, values and patterns accepted by scientists. Within it is placed the practice of 'normal' science, whose task is to solve various 'puzzles and riddles' until anomalies emerge, that is, facts that cannot be explained on the basis of the matrix. These views have tried to reconcile (I. Lakatos) by seeking a certain synthesis of their approaches, while proclaiming their own reflections (Stankiewicz, 2007).

With regard to economics, the concepts of scientific research programmers are pointed out, in the structure of which it is necessary to distinguish between a "hardcore" forming a set of fundamental and conditionally unquestionable assumptions, the content of which is subject to slow changes; and a "protective belt", which surrounds the "hardcore" and which consists of auxiliary hypotheses, modified according to the needs of defending the foundations of the scientific research program and whose content must be frequent.

The resultant of all the views cited allows the idea of the paradigm of the new neo-institutional economics to be outlined. It refers to a holistic cognitive approach imposing the need to use a modeling method (more specifically, a benchmark model) allowing to focus attention on the relations between the parts and the whole, to search for a coherent unity of phenomena and to follow the process of social evolution. It is based on a set of elements that constitute the 'core' of the paradigm and the 'safety belts' that constitute its environment. This implies the need to make interdisciplinary use of the contributions and achievements of other scientific disciplines, especially technology, law, sociology, social psychology, pedagogy, or even neurology, anthropology and other sciences (Stankiewicz, 2007).

At the core of the New Institutional Economics paradigm are four structural elements: "social ceremonies" and "technology" (corresponding to T. B. Veblen's ideas of the business world and the industrial world); "philosophy" (referring to the views of C. E. Ayres, J. Dewey's[7] pragmatism and instrumentalism) and "environment" (based on the views of K. Polanyi and his economic anthropology). Each of these elements has its own "safety belt" which is its environment and characterizes its essential determinants. "Social ceremonies" are described by the determinants: institutions, beliefs and values. "Technologies", in turn, are described by the determinants: tools and qualifications. "Environment", on the other hand, is concretized by the determinants: flora, soil, fauna, climate. "Philosophy", on the other hand, is described by the determinants of social legitimacy (referring to the criteria of social legitimacy – "social legitimacy" by W. C. Neale[8]); participatory democracy (based on the essence of participatory democracy – "participatory democracy" by M. T. Tool[9]) and sufficiency (referring to "sufficiency" by K. Polanyi).

[4]Imre Lakatos (1922-1974) – Hungarian of Jewish descent. Methodologist. Author of the works: "Essays In the Logic of Mathematical Discovery" (1961), "Criticism and the methodology of scientific research Programmes" (1968).

[5]Karl Rajmund Popper (1902-1994) – Austrian physicist and logician. Author of the works: "Logik der Forschung" (1935); "The Poverty of Historicism" (1957) and "Objektive Knowledge "(1972)

[6]Thomas Samuel Kuhn (1922-1996) – American historian and philosopher of science. The author of the work "The Structure of Scientific Revolutions" (1962)

[7]John Dewey (1859-1952) – American, supporter of instrumentalism (varieties of pragmatism). He brought his ideas to institutionalism.

[8]Walter Castle Neale (1925-2004) – author of theorems on the criteria of social legitimacy.

[9]Marc R. Tool (1921-2018) - creator of the concept of participatory democracy. Author of "The Discretionary Economy: A Normative Theory of Political Economy" (1979), and "Essays in Social Value Theory: A Neoinstitutionalist Contribution" (1986). He was the editor of "An Institutionalist Guide to Economics and Public Policy" (1984).

The formula of the presented paradigm of institutional economics assumes that the observer of reality who intends to study it cannot be neutral and will not be objective, because he is always a representative of a particular culture. In doing so, he or she must take into account the achievements of many sciences in order to make value judgments. With this in mind, attempts are being made to refine it (F. G. Hayden[10], G. M. Hodgson[11]). In the first instance, the concept of a matrix array of the social system is promoted, composed of streams and resources with no single denominator, whose individual cells integrate relations of free benefit, distribution and exchange (F. G. Hayden). Four issues are also introduced into the paradigm of institutional economics: the concept of exchange understood as the transfer of property rights; the institutions of the market seen as a set of social institutions in which goods are exchanged with particular regularity; the enterprise as a creature that ensures the reduction of opportunity costs, operating under conditions of uncertainty and practicing economic calculation; expectations that boil down to the demand for the creation of institutions conducive to the formation of a mixed socio-economic arrangement in the future, in which tradition, market and planning will coexist (G. M. Hodgson).

An important aspect of neo-institutionalist views is their orientation towards cultural premises (S. Huntington[12]), which, alongside ideological and economic premises, can be the generator of many threats. The multidimensionality of culture, in their view, increasingly causes the differentiation of the world, strongly influencing ideology and economics, succumbing also through feedback to their influence. However, it should also be borne in mind that, despite the growing importance of cultural premises, there is – as they point out – a persistence of national cultural economics on the basis of psycho-physical and organizational characteristics (Huntington, 2001).

The output of the institutional economics stream was considered to be usable for a new view of economic theory. The considerations undertaken in its field should be focused both on the theory of the functioning of the mechanisms of social economics, including: the controversies and dilemmas around its fundamental problems; and the institutional view of their resolution. Such a logic of approach to economics should be subordinated to addressing, inter alia, such problems as: the theory of design of socio-economic mechanisms, namely: the concept of motive congruence (L. Hurowicz[13]) – that is, the desired state of behavior of participants in a social mechanism; the principle of disclosure (R. Myerson[14]) treated as a technical concept, allowing the construction of general theorems on the feasibility of using resource allocation under conditions of incentive constraints and economic problems burdened by adverse selection and moral hazard; and implementation theory (E. Maskin[15]) emphasizing the completeness of the elements of a theory to ensure its effective coherence. Opportunities are also indicated to invoke the achievements of public choice theory and political cycle theory, attempting to explain changes in the structure of institutions under the influence of competition between individuals and organizations in the political market.

Recalling the indicated determinants of the institutional outlook on the challenges to civilization emerging before European society, the logic of their identification, analysis and characterization can be put into a set of overlapping global development problems of Europe within the idea defined by the framework of

[10]F. Gregory Hayden – American, professor at the University of Nebraska. The author of the concept of the social system matrix, composed of flows and resources, without a uniform denominator. The individual cells of the matrix integrate the relationships of free benefits, distribution and exchange. He treated the matrix table as a helpful tool for analysts and planners.

[11]Geoffrey M. Hodgson (1946-) – Englishman, lecturer in economics at British, French, Austrian, Swedish, American and Japanese universities. Author of works: "Economics and Institution. A Manifesto for a Modern Institutional Economics" (1989); "Economics and evolution: bringing Life back into Economics" (1993); "Evolution and Institutions. On Evolutionary Economics and the evolution of Economics" (1999); "The Evolution of Institutional Economics: Agency, Structure and Darwinism in American Institutionalism" (2004).

[12]Samuel Phillips Huntington (1927-2008) – American political scientist, author of publications "The Clash of Civilizations?" (1993), "The Clash of Civilizations and the Remaking of World Order" (1996).

[13]Leonid Hurowicz (1917-2008) – Polish-American economist of Jewish origin. Nobel Prize winner. Author of the theory of designing mechanisms presented in the works: "The Theory of Economics Behavior" (1945); "On the Concept and Possibility of Informational Decentralization" (1969); "The Design of Mechanisms for Resource Allocation" (1973); "Designing Economic Mechanism" (2006).

[14]Roger B. Myerson (1951-) – American professor of economics. Nobel Prize winner. It is one of the world's leaders in mathematical economics, econometrics, mathematical economics and game theory. Author: "Game Theory: Analysis of Conflict" (1991), "Probabilistic Models for Economic Decisions" (2005).

[15]Eric S. Maskin (1950-) – British professor of economics. Nobel Prize winner. Author of fragments of works: "Economic Analysis of Markets and Games" (1992); "Recent Developments in Game Theory" (1999); "Planning, Shortage, and Transformation" (2000).

the paradigm of new institutional economics. In the first place, they are formed by a core reflecting a set of population resource factors, a set of capital resources (material, financial) and a set of relations. The first set includes demographic issues, population allocation and migration, labor resource activity, and poverty and malnutrition. Second, on the other hand, material issues viewed through the prism of availability of raw materials, industrial and agricultural production and the conditions of its implementation and effects. In turn, the third from a set of socio-cultural, scientific-technical and balance sheet relationships (Dziurny, 2020; Rosling et al., 2018; Schwab, 2018).

3 GLOBAL CHALLENGES FOR EUROPE

Focusing only on those challenges that relate to social and economic issues, it should be noted that they have been addressed for more than half a century by scholars, practitioners and politicians representing many of the world's leading opinion formers, such as the Club of Rome, the Rand Corporation or the National Intelligence Council. Virtually every country has established centers dealing with the issue of civilizational challenges. In Poland this is the Forecasting Committee "Poland 2000" at the Presidium of the Polish Academy of Sciences. Opinions of all these institutions have shown that the contemporary world, at the stage of transition from the industrial to the information and information age, reveals clearly visible global development megatrends, which outline the civilizational trends occurring in the contemporary world economy, characterized by relative permanence, anticipation and universalism, towards which an economic society cannot remain indifferent. Their list must include phenomena relating to population (demographic, migration, health, poverty, ...), social reproduction (raw material, material, capital, economic relations...) and civilization (scientific and technological progress, cultural progress, ...) (Dziurny, 2020).

The problems indicated, each of which generates development challenges on the one hand and development threats on the other hand, also concern Europe (Krzynówek et al., 2009; Żukrowska, 2015). The continent, which currently numbers 46 internationally recognized countries, 4 countries with limited international recognition and 7 dependent territories, is not homogeneous according to the commonly accepted criteria of their characterization and assessment. The vast majority of them are in the group of more developed countries (high, medium), but some are also in the group of less developed countries. In the land area of the world, which is about 130.1 million km^2 (of which only about 30% is inhabited), the European continent covers over 22.1 million km^2, which places it on the third position in the world (Roc, 2021).

3.1 Challenges to Population Resources

The great challenge facing the European community is to address the population problem at all levels of its manifestation, that is, demographic, allocation and migration, the productive capacity of labor resources, and the vices of life such as poverty and malnutrition. On most of them, it has more positive overtones than in the world as a whole and in the group of less developed countries (table 1).

Primary among the population challenges for European communities is adapting to the consequences of demographic change on the continent and globally (table 1). At present (beginning of 2022), there are almost 8 billion people in the world, more than 780 million of whom live in Europe, i.e., 9.6% of the total, compared to 59.5% in Asia, 17.2% in Africa, 8.3% in Central and South America, 4.7% in North America, 0.6% in Australia and Oceania. The achievement of such a large human population, despite frequent crop failures, devastating wars and major epidemics of infectious diseases, was largely the result of civilizational advances in medicine favoring the control of many infectious diseases, improved life hygiene and, consequently, a reduction in infant and child mortality and an extension of human life. On the other hand, the uneven distribution of the world's population, in relation to the level of development achieved in the various regions of the world, makes it necessary for Europe to counter the excessive influx of emigrants (Dziurny, 2020).

An analysis of demographic change in the 21st century shows significant population growth both globally and on individual continents (table 1). Projections (according to the UN medium projection variant) assume that population growth will occur at a rate of around 0.5 billion per decade. It is estimated that the population will be over 8.5 billion in 2030 and around 9.8 billion in 2050, rising to around 11 billion in 2100. This situation will occur despite the fact that the growth rate of the world's population overall is declining, while it is increasing significantly in the regions least able to provide health, food, stability, work and prosperity to an increasing number of people (Simon et al., 2010; Roc, 2021).

The greatest population growth is and will continue to be in the developing world, which will exacerbate many of these countries' development issues,

Table 1: Characteristics of the European population in relation to world regions (Roc, 2021).

Description	2000	2010	2020
Population in millions			
WORLD	6127	6958	7795
More developed regions	1171	1235	1286
Less developed regions	4956	5723	6509
Europe	726	737	748
Percentage of working people at risk of poverty by international poverty line (in %)			
WORLD	18.9[1]	14.0	6.6
Sub-Saharan Africa	50.5[1]	45.5	36.7
South Asia	31.3[1]	22.6	8.7
Europe	0.1[1]	0.0	0.0
Prevalence of malnutrition (in %)			
WORLD	12.4[1]	9.2	9.9
Sub-Saharan Africa	24.6[1]	19.4	24.1
South Asia	20.5[1]	15.6	15.8
Europe	<2.5[1]	<2.5	<2.5
Percentage of people using drinking water distribution (in %)			
WORLD	66[1]	71	74
Sub-Saharan Africa	20[1]	22	30
South-east Asia	52[1]	54	57
Europe	90[1]	91	94

Notes: 1 – year 2005

especially in the areas of education, housing, food and water supply and employment. If at present, i.e., at the beginning of the third decade of the 21st century, the birth rate is 10.9 persons per 1 000 population in the world (0.6 persons in more developed regions and 12.9 persons in less developed regions) and -0.7 persons in Europe, then in the middle of the 21st century, it is projected at 5.6 persons in the world (-1.8 persons in more developed regions and 6.7 persons in less developed regions) and -2.3 persons in Europe. The emergence of this situation is influenced by the level of socio-economic and cultural development of society, which is conducive to a successive increase in living standards. It has also become apparent that a very low human birth rate is taking place - and will continue to do so - primarily among people belonging to the Western cultural sphere, who now account for around 13% of the world's population (Camdessus, 2019; Roc, 2021).

In countries with established consumer lifestyles, high automation of production, high levels of education and qualification of people, and satisfactory financial opportunities, two negative correlations can be seen. The first – the higher the standard of living, the lower the birth rate and the second – the lower the level of economic development, the higher the death rate. These trends lead to an increase in people's life expectancy, albeit on a markedly different scale. Life expectancy is projected to reach 77 years by the middle of the 21st century, with almost 84 years in more developed areas and almost 76 years in less developed areas (Roc, 2021).

Projections for Europe assume an average life expectancy of almost 83 years in this period. This means the consolidation of the trend of aging of the European population, which is the result not only of low birth rates, but also, in some countries of the continent – formerly belonging to the group of planned economy countries – changes in the structure of the economy, lack of life stability (no jobs, no housing, low wages). Now, it is at the beginning of the third decade of the 21st century, due to the effects of the COVID-19 pandemic, that a trend is beginning to emerge, reflected in a noticeable reduction in life expectancy in many countries (Gorynia and Mroczek-Dąbrowska, 2021).

The population issue must also be viewed from the point of view of its impact on the size and structure of the labor force (workforce), its age and labor force participation and allocation. Countries with a large post-working-age population and a relatively small working-age population, as well as a small percentage of women and children, reveal aging tendencies. Hence, this group of countries – which also includes European countries – reveals a growing demand for labor generating, at the same time,

large-scale migration processes from less developed areas with larger working-age populations in under- and medium developed countries constitutes the main source of cheap labor for developed countries.

This direction of perceptions and evaluations of this phenomenon is confirmed by analyses of the state and projections of the demographic burden, i.e., the scale of the percentage ratio of the number of non-productive (pre-productive and post-productive) to productive people. Considered at the level of labor force reproduction, they indicate that the population is a function of natural increase, i.e. the difference between the number of births and the number of deaths. It is influenced by many economic, social and cultural factors. The birth rate is mainly determined by the fertility rate and the length of a woman's childbearing years. Models of demographic change assume a 15- or 25-year reproductive period. A 15-year reproductive period with an assumed 3.5-year birth interval results in a fertility rate of 4.3 children, while a 25-year reproductive period with an assumed 1.5-year birth interval results in a fertility rate of 16.7 children. In practice, the highest fertility rates are eleven / twelve children. Another important factor is the increasing lifespan of people. The existing state and forecasts of this phenomenon signal a growing threat expressed in the necessity of securing the material basis of existence by a decreasing population of productive people with a growing population of non-productive age (Roc, 2021).

Analysis of old-age dependency estimates and projections shows that since the third decade of the 21st century, the number of people of working age is decreasing relative to the number of people of non-working age. This situation is taking place both in the group of more and less developed countries, with quite significant differences in the total and in individual groups. In the group of more developed countries, these proportions are the worst at present – according to data for 2020, there are 45.7% and 46.4% of the total working age population in Europe, with projections of this figure for the middle of the 21st century at 25.4% in Europe and 36.2% in North America. This situation is primarily a consequence of increasing life expectancy, far less a consequence of population growth expanding the stock of people of pre-working age (Roc, 2021).

At the end of 2020, the world's labor force (employed and unemployed) amounted to almost 3.5 billion people, with significant differences in territorial allocation. Asia (excluding Central Asian and Arab countries) and the Pacific had the largest share with 57.1%, followed by Africa with 14.3%, Europe and Central Asia with 12.8%, Central and South America with 8.6%, North America with 5.5% and Arab countries with 1.7% of the total labor force (Roc, 2021).

The existing population situation, also contributes significantly to increasing migration phenomena – both internal and external. On a global scale, external migrations taking various forms of exile, above all economic, political, military, cultural, ethnic and religious, are particularly dangerous. Increasing differences in demographic structure between developed countries, progressing globalization processes and political and military tensions between the world and developing countries contribute to their widening scale. They are also reinforced by civilizational advances in digital communication and mobility and the rise of nationalist attitudes in many regions of the world.

External migration processes give rise to numerous direct and indirect threats and are a breeding ground for many social tensions and conflicts. Direct threats include problems such as food, employment and unemployment, environmental devastation and urbanization. Indirect effects, on the other hand, are mainly: the severance of traditional social ties; changes in the system of social norms and the value system; a reduction in internal security; and an increase in violence and crime.

The scale of the external migration problem is significant. According to UN data, in 2020 the number of migrants in the world will be over 270 million people (almost 3.5 percent of the total world population), which compares to 2000 (150 million people) and 2010 (214 million people) a marked increase (Wor, 2022).

An increasing proportion of the migrant population are refugees, i.e., people who have been forced to leave their home country because of wars and persecution. Estimates, according to the United Nations High Commissioner for Refugees, place their size at the beginning of the third decade of the 21st century at around 85.5 million people, including 25.6 million men, 22.3 million women and 34.6 million children and young people. Currently (at the end of May 2022), the number of refugees has exceeded 100 million people. A significant proportion of them are choosing Europe as their destination. The scale of the problem on the European continent is currently being expanded by the refugee situation from Ukraine. According to information from the country's border services, more than 6 million people have left the country (as of the end of May 2022) – of whom more than 4.3 million have entered Poland. In addition to this, the consequence of Russia's barbaric assault on Ukraine has resulted in a large internal refugee population estimated at over 6 million people (Wor, 2022).

A certain novelty in the shaping of the external migration flow is the so-called "climatic migration", which is increasing year by year, contributing to an increase in the number of emigrants, for climatic and natural reasons.

Migration patterns outlined in the first decades of the 21st century indicate that the largest population movements have occurred within individual regions of the world, rather than between continents. Internal continental migration in Europe now significantly exceeds the influx of Africans and Asians to the old continent. It is generally characterized by a direction from economically backward countries and countries experiencing development difficulties to more developed countries. This means that the West is facing increased migration and refugee flows from poor or conflict-prone regions of the world. In addition to this trend, some changes in migration routes can be observed. One of the leading ones is the route of the influx of migrants to France, Germany and the UK (Sachs, 2009).

A major population problem at the turn of the 20th and 21st centuries is meeting health and epidemic challenges – both globally and in Europe. These problems have accompanied man since the beginning of his existence on earth. Infectious diseases have proved to be the most important threat to human health, resulting in enormous human morbidity and mortality. They have not lost their relevance even today, just in the decades of the late 20th and early 21st century. If, worldwide, there were 1043 events resulting in 19.3 million infected people, including 162 000 deaths, in Europe there were only 104 events resulting in 189 000 infected people, including only 4 000 deaths. By far the greater health devastation worldwide as well as on the European continent was caused by the SARS-CoV-2 virus pathogen identified in November 2019 as an epidemic, since March 2020 it has been referred to as pandemic COVID-19. It has contributed to the illness of more than 368 million people and the death of more than 5.6 million people by the end of January 2022. Europe proved to be the area of dominant outbreaks after the American continent. Out of 121.7 million infected, more than 1 609 000 people died. Community To the greatest extent, according to the number of deaths, this situation affected the communities of Russia, the UK, Italy, France, Germany, Poland and Spain. It has caused global social, political and economic disruption (Wor, 2022).

The COVID-19 pandemic revealed a wide range of areas of potential risk. It has contributed not only to high morbidity and mortality but also to the existence of many negative economic impacts across sectors, all entities and all forms of human activity. It has necessitated many new phenomena, such as remote working, mandatory quarantines shortages of emergency medical, health and safety equipment for citizens. In the economic sphere, it has caused a global weakening of economic activity. Supply shortages, largely caused by panic buying, became apparent. There have been numerous disruptions in the supply chains of consumer and investment goods. In succor of this situation comes the concept of sharing resources and services. In the social and living sphere, society has revealed negligence in the provision of clean air in dwellings, as well as overcrowding. The availability of measures to improve this situation has become an important issue. Numerous controversies were revealed by the pandemic in the social sphere. According to a section of the world community, the pandemic is being used to impose a unified vision of the world and subject people to total control. These opinions correspond to the facts in many countries of the modern world, where the freedom of their citizens has been drastically curtailed. Fear of a pandemic has set in motion processes of sanitization (segregation, selection) and the practical abolition of fundamental human rights and the imposition of total surveillance. This is accompanied by the emergence of disinformation and conspiracy situations, giving rise to attitudes of xenophobia and racism. They have also contributed to the emergence of many anti-vaccine attitudes.

The consequence of the current and future health and epidemic situation of the world is the accumulation of numerous developmental barriers and risks. These are psychological-biological, psychosocial, as well as civilizational (technical, technological) and spatial in nature. Their limitation and overcoming forces the world community to creatively oppose these phenomena in all areas of human life. Health care and the pharmaceutical market were affected first; the labor market and education followed (Solarz and Waliszewski, 2020).

The pandemic also revealed many new areas of social activism. The response to the barriers and threats in these areas has been the search for solutions to the challenges they bring. Its practical implementation has been facilitated by the development of digital economy technologies. The exchange of resources has taken on a completely different dimension by embracing further sectors of the economy. The idea of economic rationality, both in terms of consumption and investment, has also returned.

An important problem of the contemporary world – including Europe – that is directly related to the population problem is the issue of poverty and deprivation. They are a consequence of development

inequalities, translated into differential labor income and inequalities of ownership of capital and property. They manifest themselves not only at the regional and national levels, but also at the individual level. For Europe, it is important to consider this issue first and foremost at the individual level, as it leads to the generation of hunger and malnutrition (Landes, 2015).

Poverty is now defined as a systemic risk, determining the poverty level of all those whose income barely exceeds the extreme poverty threshold and who consequently form the poor layer. For them, the need for social inclusion and the improvement of their living conditions and cultural diversity is recognized. In this process, appeals to the principles of: respect for the dignity of every human being; equality and justice; respect for all human rights and the letter of the law; and ensuring the sustainability of the democratic system.

Poverty, as already pointed out, is always linked to malnutrition (hunger) and also to development (growth). These links and relations reveal both the traditional approach (poverty – unsatisfied material needs; hunger – insufficient food for all; development – linear from tradition to modernity) and the alternative approach (poverty – unsatisfied material and immaterial needs; hunger – sufficient food, with a poor system of distribution and right to food; development – differentiated). Its externalization on a global scale is the determinant of the level of GDP per capita per day, referred to as the international poverty line. According to the World Bank's methodology, a daily expenditure level of less than USD 1.90 per capita (at purchasing power parity in 2011 prices) is considered poverty (Roc, 2021). In Europe, on the other hand, poverty is defined, following the definition in force since 1984, as a situation that refers to individuals, families or groups of people whose resources (material, cultural and social) are limited to such an extent that it excludes them from a minimum way of life in the country in which they live. Following this approach, Eurostat has generated an indicator of poverty and deprivation in Europe, corresponding to nine points, namely: inability to incur unexpected expenses; inability to go on a week's holiday away from home; having arrears (e.g. mortgage, non-payment of rent, etc.); inability to buy every second home; and inability to live in a country where they live; inability to buy a meal every other day that includes meat, chicken, fish or a vegetarian equivalent; inability to heat the home adequately; not having a washing machine; not having a color television; not having a telephone; not having a personal car (Dziurny, 2020).

A significant proportion of the global community is affected by poverty, even though the number of people living in poverty decreased by about 200 million during the first decades of the 21st century, while the world population grew by about 1.5 billion people. According to the World Bank, in 2018 poverty levels have fallen to 8.6 percent and are estimated to continue to decline. Currently, the phenomenon of poverty affects a large swathe of the population as at least 750 million people were living on less than USD 1.9 a day (Wor, 2022).

An analysis of the level of poverty – measured by the percentage of people at risk of poverty – on a world scale, in the first two decades of the 21st century, shows (table 1) a significant reduction.

The poorest region in the world remains sub-Saharan Africa and South Asia. In 2020, these two areas accounted for about 85% of global poverty, with sub-Saharan Africa accounting for 36.7% (over 420 million people) and South Asia 8.7% (about 200 million people). In the rest of the world, the percentage of poverty does not exceed 5%. The situation is best in North America and Europe (Roc, 2021). The prospect of eradicating poverty – according to the institutions responsible for this task – by 2030 does not seem realistic. This is because it involves providing the poor with humanitarian aid as well as investment aid, especially in building human capital and promoting growth that takes into account the interests of the poor.

Population issues, largely as an aftermath of poverty and deprivation, also involve feeding the global community (Caparrós, 2016). Due to a mismatch between food production and its desired consumption, a significant proportion of the world's population is undernourished or starving. Although these phenomena manifest themselves in the practice of most countries of the world, they are concentrated only in certain regions of the world. The level of malnutrition, as defined by the prevalence rate of malnutrition expressed in %, although clearly decreasing globally (table 1), remains high in sub-Saharan Africa and South Asia. The best situation is in North America and Europe where it has remained below 2.5% for years.

According to the FAO, the World Food and Agriculture Organization, there are currently more than 1 billion hungry people in the world. In turn, estimates by the UN Food and Agriculture Organization cite a figure of 2 billion (about 30% of the total) of the world's population who are undernourished – of whom more than 830 million people are starving, of whom more than 650 million suffer from extreme hunger – 150 million of them children. It is estimated that the level of 400 million undernourished

will not be reached until 2050. Sub-Saharan Africans account for the largest proportion of the undernourished. Hunger and malnutrition are characteristic of less developed countries, but it also affects communities in developed countries. Estimates suggest that 16-20 million people are affected in this group of countries. These include some countries in the West, as well as in the East, especially those that are transforming their economies (Stowarzyszenie Demagog, 2022).

Following the division made, it should be noted that the problem of malnutrition mainly affects underdeveloped countries, where the main cause of food shortages in these countries is the rapid growth of the population, disproportionate to the possibilities of increasing agricultural production (Stachowiak and Stachowiak, 2022).

The consequences of hunger are numerous diseases, often leading to death. The FAO estimates that around 30 million people die every year from hunger and malnutrition. In practice, this means that someone dies of hunger every four seconds in the world. This situation occurs not so much because there is a physical shortage of food, but because poor countries do not have the financial resources to purchase it from countries with large stocks of agricultural commodities. For a large part of the world's population, hunger and malnutrition are no longer present in their lives, but for the rest it is still present. Today, hunger is still a daily reality and has many dimensions.

Given the large increase in population and per capita income, the world's ecosystem is threatened by human activities, including those related to food production, processing and storage. Its consequence can be the phenomenon of the scarcity of healthy and potable water. At the beginning of the 21st century, some 1.1 billion people did not have access to it – mainly in Africa and Asia. This situation is linked to a decline in groundwater levels, which has become apparent in large areas of China, western Asia, the Middle East, the former USSR and the western United States. More than half of the world's rivers are over-exploited and significantly polluted. A large proportion of the world's population (around 2.6 million people) lives without sanitation. Analyses of the availability of safely managed water distribution point to this issue. These are characterized by far-reaching variations across the globe. If this does not pose a significant problem in North American and European countries, one does with regard to sub-Saharan African countries. The solution to this problem involves the need for official development assistance (table 1). If the situation does not change in future decades, the problem of water scarcity is likely to affect hundreds of millions of people. Due to climate change, it will be impossible to cultivate land in many areas of the world.

Reduced availability of water, generates another significant threat to the world which is soil erosion, amplified by the impact of inappropriate farming methods, inadequate irrigation and increased salinity of the land. Manifestations of these threats are increasing natural disasters on a global scale, causing significant material, financial and human damage (Stachowiak, 2004).

3.2 The Challenges of Civilization to Material Resources

The first of the problems to be addressed as a leading solution is the issue of the progressive processes of diminishing and even depleting natural resources worldwide. These have a significant impact on Europe's economic development, raising the question of how to obtain them, both physically and economically. Their characteristic feature is that they are limited and unevenly distributed. They are available from only three zones of the Earth: the hydrosphere, the atmosphere and, for the most part, the Earth's crust. They are renewable and non-renewable in nature. By 2030, cumulative resource consumption is not yet expected to significantly compromise economic development opportunities. While it is estimated that there are still opportunities to reproduce renewable resources through reproduction, assessments as to the sufficiency of mineral resources vary widely and do not present a clear-cut vision. They give both pessimistic and optimistic assessments. The former point to their deepening scarcity, due to ongoing population growth and economic development. The dominant optimistic assessments, however, point to the potential for expanding resource substitution and new technologies, saving known and currently used raw materials and creating new types of materials.

The Earth's raw material resources, in addition to being limited, are characterized by their uneven use. Only 20% of the world's wealthier people use 85% of the world's timber, 75% of its metals and 70% of the world's energy production. According to UN data, around 80% of the world's wealth is held by 15% of the population. It is also legitimate to conclude that the size of the world's resources is limited, although still not fully known, which should be seen as a warning. This situation is particularly noticeable with regard to fossil energy resources. The structure of their recognized resources, estimated at 1057 billion tons of conventional fuel, is dominated by coal (around 63%), followed by liquid fuels (around 19%) and gas

(around 17.7%) (Sachs, 2009).

At the beginning of the third decade of the 21st century (2022), the recognized reserves of hard coal and lignite were estimated at 860 billion tons, which should ensure their availability: hard coal within a horizon of 400 years, and lignite within a horizon of 140 years. Oil reserves, on the other hand, are estimated at around 182 billion tons, which should last for around 160 years. In contrast, the world's proven natural gas reserves are estimated to be close to 187 490 cm, i.e. its availability over the next 60 years. As for uranium, its proven reserves are estimated at 2.44 million tons. In the perspective of the next few decades, the estimated resources will decrease, with a change in the structure of the use of individual raw materials. Natural gas is expected to play an increasingly important role in the economy and may gradually displace hard coal, lignite and oil (Wor, 2022). This trend is confirmed by an analysis of changes in the supply and consumption (extraction) of energy carriers and changes in the production (extraction) of major natural resources (table 2). A separate group of energy raw materials are the so-called renewable sources, the resources of which are basically stable.

The separate major problem of the world economy is the issue of the exhaustibility of many types of natural resources as a consequence of their extraction caused by production needs. It is estimated that currently identified estimated reserves of fossil raw materials – treated as primary raw materials – will be mostly exhausted in the next 60-140 years. A more optimistic approach to the world's natural resources is a dynamic one, based on the belief that these resources do not have a finite size, that they are essentially a function of human knowledge and capacity. This means giving priority not to the physical size of natural resources at any given time, but to an awareness of the possibility of meeting needs for them on the basis of those resources that have already been identified and those that are yet to be discovered, and those that can be secondarily recovered.

The solution to the raw material problem – which is at the same time a global problem – is only possible with a comprehensive approach to it, that is, with a combined solution to the raw material problem with environmental, demographic, food and general development issues. Being aware of the rarity of non-renewable resources and their finiteness, it seems expedient and desirable to direct human economic activity, based on price mechanisms, towards rationality of conduct, consisting in the search for new technologies using relatively cheaper resources, the activity of economic authorities – i.e. the state – towards desirable ways of using the environment on the basis of both administrative and economic instruments: and towards all those activities which will lead to a physical reduction of their consumption and the generation and absorption of energy- and material-saving techniques and technologies (Toffler, 2003).

The problem of the exhaustibility of economic resources at the same time as their increased consumption has forced the reconciliation of economic development with the solution of environmental problems, also in its ecological dimension. At the same time, this means that the use of the environment, which is growing along with economic development, is leading to tensions not only as a result of the increasing scarcity of natural resources, but also in view of its destruction and pollution. The consequences of both natural and technical catastrophes, as well as the consumption behavior of households and investment behavior of businesses, contribute to this.

The processes of global economic reproduction – in the material sphere – are significantly affected by natural disasters, of which the following should be mentioned: extreme temperatures and the resulting droughts and fires, floods and storms, as well as volcanic eruptions. These generate considerable material damage, often affecting large numbers of people, some of whom lose their lives. This is indicated by the data on this phenomenon for the period 1990-2011 (table 3).

One of the natural threats facing the world community is the phenomenon of warming. This climatic phenomenon is the result of the world's increasing industrialization, urbanization and the way people live. The increase in heat on Earth is seen by climatologists as an anomaly caused by the impact of human civilization and industrial carbon dioxide emissions. It has been calculated that in 2000, the carbon dioxide content was 30% more than in 1750. If carbon dioxide concentrations were to double by 2100, the Earth's average temperature would be expected to rise by 1.9 to 5.2 degrees Celsius. Such a significant warming of the climate will exacerbate current climate threats and lead to catastrophe on Earth. The years at the end of the twentieth century brought an exacerbation of certain relatively new environmental phenomena, such as urban air pollution, acid rain, the so-called ozone hole, the greenhouse effect, sea pollution, drinking water shortages, declining forest areas and changes in the world's biological resources. They are the consequence of human activity and the means it uses. They are characterized by the fact that they are mostly international in scope and global in dimension. They are all closely linked – in a feedback system – to economic development and global population growth.

Table 2: World production of fossil fuels, major natural resources, industrial products and electricity (Roc, 2021).

No	Specification	2000	2010	2020
1.	Hard coal in million tonnes	3587	6510	6723
2.	Oil in million tonne	33447	3615	3928
3.	Natural gas	97	127	155
4.	Cement in million tonnes	1660	3280	4100
5.	Crude steel in million tonnes	849	1034	1319
6.	Refined copper in million tonnes	14.8	19	24.5
7.	Primary aluminium in million tonnes	24	41.8	65.2
8.	Bauxite in million tonnes		236	371
9.	Wood (coarse) in hm3	3482	3587	3915
10.	Electricity in TWh	15481	21516	27044

Table 3: Natural disasters in the world by type from 1990 to 2011 (Roc, 2021).

SPECIFICATION	Number of incidents	Fatalities in thousands	Persons affected	Damage value in USD million
Flood	2858	161	2612487	430434
Drought	338	4,5	1192872	64907
Storm (tornado)	2092	386	659609	736218
Earthquake (seismic activity)	603	805	115543	637044
Fire	253	1,6	5548	43541
Extreme temperatures	350	158	96671	48703
Volcanic eruption	120	1,5	3699	559

They also have in common that their consequences are not fully recognized (Stachowiak and Stachowiak, 2022).

A consequence of natural disasters has been the growing threat of the extinction of some 11,000 animal species as a result of irreversible environmental transformation. Specifically, this threat affects around 25% of all mammal and reptile species, 20% of aquatic animals, 30% of fish and 12% of birds. The increase in this phenomenon is confirmed by analyses of the extinction of endangered species. If the global extinction rate for endangered species (based on the Red List of Threatened Species) in 2020 was 0.73, the most alarming situation was in Central Asia (0.93), North Africa (0.87), Europe (0.84) and North America (0.84). Forests are also at risk of destruction. According to the World (UN) Food and Agriculture Organization (FAO), approximately 40 percent of the world's old-growth forests could disappear over the next 10 to 20 years (Roc, 2021).

Numerous technical and technological disasters also have a significant impact on environmental degradation. They affect all areas of the globe. They are the cause of industrial accidents, accidents in non-industrial facilities and transport accidents (land, sea). They also affect a significant proportion of the population locally, often contributing to their deaths. They caused damage of a high value, which also necessitated further expenditures for their removal.

In view of this situation, the challenge of the future is to address the economic, technical and technological development of individual national economies and the global economy as a whole, without destroying its natural base. The challenge of the future should be to act pro-ecologically. It is becoming necessary to reorient the awareness that it is not the progress of civilization that leads to an ecological disaster, but its inappropriate use.

In the modern world, environmental degradation is a threatening and real phenomenon, but not inevitable. Mankind has an opportunity to prevent it effectively. In the first instance, it should learn about the causes and consequences of environmental degradation and strive to make proper use of the progress of civilization on a global scale. It is also indispensable to make full and effective use of all methods and possibilities of environmental protection. It is also desirable to work towards the elimination of technologies that pollute the environment in a way that endangers life and health, and instead to disseminate technologies that do not poison or pollute the environment. However, this implies a cost. The most synthetic expression of these should be a reduction in the rate of economic growth. However, solving the environmental problem is not only an economic issue, but also a political and institutional one.

One of the important problems plaguing the world at the beginning of the third millennium is the issue of

the regional mismatch between food production and consumption. If we have a situation of a balanced world food market on a global scale, however, in some regions we are dealing with its far-reaching disharmony (table 4). This manifests itself – at close to equilibrium physical availability – as economic inaccessibility to food. As such, it gives rise to numerous regional and local pockets of malnutrition and hunger. This situation is influenced by a range of factors, from climatic to structural, economic and demographic.

When analyzing the physical side of agricultural production and, consequently, food production, it is necessary to point out the far-reaching variation in it across the world. The situation on the African continent is the worst from this point of view. A far from satisfactory situation also applies to many countries in Latin America and Asia. The primary cause appears to be climatic disturbances: harsh winters, droughts, floods and storms. The second, also very important, is the inability of agriculture to increase food supply due to its backwardness, which is determined by the size and structure of the stock of arable land and its trends, technical equipment, mineral fertilization, land reclamation, and government food policy. The economic unprofitability of production is also a frequent cause, which occurs especially under conditions of increasing energy intensity of production. The fact that agricultural production capacity is being exhausted is also not insignificant. All these stoppages are reinforced by the persistence of poverty in many regions of the world.

The causes of this situation are to be found in particular in unfavorable changes to climate and soil conditions. They are therefore primarily objective in nature. However, they have also been caused to a large extent by the overexploitation of pasture and arable land, increasing demographic pressure and the desire to increase the production of pro-export monoculture crops.

Combating these phenomena must be considered humanity's most urgent and important task. Solving this problem is already posing many difficulties today. It will be all the more difficult to solve in the future in view of the demographic forecast scenarios. Meeting this problem, even if it is technically possible, will be limited by factors of an economic, infrastructural, political and also health nature. At present, the most important barriers to the growth of agricultural production are: the inevitable decrease in the area of agricultural land and, consequently, in the food area; the failure to comply with agrotechnical principles; the growing deficit in fresh water; the persistence of an archaic agrarian structure, as well as low agricultural productivity in many regions of the world; the occurrence, due to climate change, of the phenomena of floods and droughts leading to food disasters; the manner of food distribution and the general development problems of the global economy (Małysz, 2009).

The phenomenon of hunger and malnutrition is closely linked to the mismatch between regional food production and consumption. On the production side, a range of factors – from climatic to demographic to economic – influence this. On a global scale, the existing inequalities in food production and caloric intake make it possible to divide all countries into five groups according to food availability. These are: first - established food powers (14 highly industrialized countries); second – new food exporters (including Brazil, Uruguay, Paraguay, Argentina, Russia, Ukraine); third – self-sufficient countries (basically: China, India, Pakistan); fourth – importers of expensive food (Japan, South Korea, Switzerland, UK, Gulf kingdoms); and fifth – poor and food insecure countries (countries in Central America, Central Asia, North and Sub-Saharan Africa).

Addressing the food issue requires a number of undertakings. reflected in the global community's pursuit of food security, which boils down to ensuring the physical and economic availability of food and the healthiness of food products.

Evaluations into physical access to food indicate that solving this problem poses many difficulties, and it becomes all the more difficult in the future. Indeed, if demographic projections are taken into account, global food production should increase by 75-100% over the next 25 years if there is to be enough food for the entire world population. If meeting this problem from a technical-agronomic point of view (i.e. physical availability of food) is possible, it will be limited by factors of an economic (distribution), infrastructural, as well as political and health (availability of healthy food) nature (Górecki and Halicka, 2013).

3.3 Relational Challenges in Europe

By treating the relational challenges as a complement to the two previously identified population and material challenges, it is necessary to give them a balancing character. They must be seen at the level of both internal development processes and external development processes. They are closely interrelated and interact with each other. The development of the world economy is closely linked to the civilizational development of world society as measured by scientific, technical, technological and organizational progress. This is due to the economic internationalization of the economy and the inclusion of ever wider

Table 4: Production of the world's major food resources (Roc, 2021).

SPECIFICATION	2005	2010	2020
WORLD			
a. Cereals harvested in million tonnes	2266	2467	2979
b. Meat production from slaughter in million tonnes	260	295	337
Africa			
a. Cereal harvest in million tonnes	142	167	204
b. Meat production from slaughter in million tonnes	13.6	16.5	20.7
Central and South America			
a. Cereal harvest in million tonnes	57	187	284
b. Meat production from slaughter in million tonnes	39.2	46.1	56.0
Asia			
a. Cereal harvest in million tonnes	1087	1227	1435
b. Meat production from slaughter in million tonnes	105.5	123	131
Europe			
a. Cereal harvest in million tonnes	427.5	405.5	546
b. Meat production from slaughter in million tonnes	51.9	56.6	64.0

areas of the globe in comparative mechanisms. It is associated with efforts to expand and increase competitiveness and the search for even more innovative development strategies. Achieving a civilizational advantage in these areas involves incurring correspondingly large expenditures (table 5). Its expression is in the reported inventions of new innovative technologies and techniques, as well as consumer and investment products.

The volume of investment in research and development activities is constantly increasing. Higher levels of outlays than the global average is taking place in North America, East Asia and Europe. Leading countries (according to 2016 data) are South Korea (4.23%), Switzerland (3.37%), Sweden (3.25%) (Japan (3.14%), Austria (3.09%), Germany (2.93%), Denmark (2.87%), Finland (2.75%) and the USA (2.74%). Significantly lower levels of outlays as a proportion of GDP are in: France (2.25%), China (2.11%), the UK (1.69%) and Russia (1.1%). In contrast, the lowest levels of outlays as a proportion of GDP are in Central Asia, Sub-Saharan Africa, South Asia and North Africa (Roc, 2021).

The variation in the number of outlays on research and development activities is also evident in Europe. The European Union countries (27) reached 2.23% of GDP in 2020, with the euro area countries (19) at 2.26%, and Poland at 1.32% (in 2000 – 0.64%). Referring to these outlay figures, it should be noted that an outlay figure of 1% of GDP only means maintaining the current level of R&D activity. The world is far from its target in this area: according to the Lisbon Strategy, the European Union countries were to reach outlays of the order of 3% of GDP by 2010, while according to the OECD they should be of the order of 2% of GDP.

The structure of R&D outlays is also far from satisfactory. In underdeveloped countries, outlays on basic research have tended to dominate, followed by those on applied research and, to the smallest extent, on development work. In contrast, in highly developed countries, outlays on development work dominated the structure of outlays.

Civilization progress has a direct impact on the shaping of economic relations on an international scale, the fullest expression of which is participation in the international division of labor, international economic turnover and international economic relations.

In turn, the social reproduction of economic relations takes place in the area of relations within a given country and in the area of foreign relations considered through the prism of foreign trade (table 6), i.e., trade exchange (imports and exports). In the first decades of the 21st century, it showed an upward trend worldwide, with the highest level of growth in exports. The dominant generator of trade exchange (both on the import and export side) was the countries of the economically developed regions – the countries of Europe and North America.

They result in trade contacts and processes of interdependence and developmental dependence.

All these hallmarks of civilizational relations affect the processes of social reproduction – in personal (human) as well as material and financial terms.

Among the important global problems of the contemporary world is the issue of world debt – both in the global, regional and national (state, country) dimensions. It is seen in terms of external (foreign, international) and internal debt (indebtedness). It re-

Table 5: R&D expenditure in relation to GDP (in %) (Roc, 2021).

SPECIFICATION	2005	2010	2015	2020
WORLD	1.53	1.62	1.7	1.73
North Africa	0.28	0.38	0.50	0.63
Sub-Saharan Africa	0.41	0.40	0.42	0.37
Latin America and the Caribbean	0.55	0.66	0.70	0.81
North America	2.46	2.66	2.70	2.72
Australia and Oceania	1.85	2.18	1.79	1.76
Central Asia	0.26	0.16	0.18	0.12
South Asia	0.70	0.70	0.55	0.59
Southeast Asia	0.64	0.75	0.85	0.92
East Asia	2.04	2.17	2.41	2.47
West Asia	0.71	0.74	0.81	0.94
Europe	1.59	1.75	1.85	1.89

Table 6: Value of imports and exports in USD million (Roc, 2021).

SPECIFICATION	2005	2010	2020
WORLD			
a) Imports	6579	15151	17589
b) Exports	6485	15116	17379
Economically developed regions (North America, Asia and Pacific (Japan, Australia and New Zealand), Europe (excluding South-Eastern Europe and CIS countries))			
a) Imports	4548	8640	9640
b) Exports	4177	8005	8910
Economically developing regions (Africa, Asia, Oceania)			
a) Imports	1927	6000	7350
b) Exports	2144	6515	7822
South-Eastern Europe and the Commonwealth of Independent States			
a) Imports	104	511	599
b) Exports	164	665	647

flects the financial side of the economic reproduction process. The economic history of the world confirms the facts of repeated occurrence of situations of external debt of national economies in the socio-political reality of the world. They have highlighted the destructive impact on the economies of individual countries, and even entire regions, of the consequences of international capital movements.

If the global debt burden at the beginning of the 1970s was around USD 90 billion, by the early 1980s it was already over USD 800 billion and by the early 1990s it exceeded USD 1.3 trillion. The 21st century opened with debt reaching almost USD 2.1 trillion. This trend continued in the subsequent decades of this century. The volume of external debt at the beginning of the third decade of the 21st century (early 2022) is estimated to be around USD 79 trillion. Both more and less developed countries were burdened by it. Currently, the leading countries in the rankings of international debt are highly developed countries (Millet et al., 2012; Gadomski, 2018). In the group of the ten most indebted countries, alongside the world's superpowers, are five European countries (table 7). Less developed countries are also saddled with less debt in terms of value, but with greater economic impact.

The emergence of an international debt crisis of a magnitude not previously recorded in the world's economic history has been due to a number of causes, both of an internal and external nature. In addition to the external debt, the internal debt of a specific country, defined as the debt incurred towards the citizens (residents) of a given country, is also important in terms of the risks of the modern world. An even more capacious category describing the indebtedness of an economy is public debt, defined as the total sum of nominal obligations incurred at home and abroad by entities belonging to the public finance sector, after eliminating all mutual obligations between its units. Public debt is a problem for all countries in the modern global economy. This is evidenced by an analysis of this problem from the point of view of its causes as well as its consequences (table 8).

An important global problem of the contemporary world has become the ability of the economy – both world (global) and regional (continental and integration groupings), as well as national – to ensure the continuity of the production of economic goods and services, the supply of quantitatively and qualitatively adequate labor resources and the expansion of international economic relations. In the practice of economic life, the response to these aspirations became the realization of social reproduction processes. The search for ways to ensure it took into account four factors: natural capital (the value of land, water, miner-

Table 7: External debt of selected countries of the world in 2020 (Słomski, 2020).

No	Country & Debt volume	Debt to GDP in USD billion	Volume of debt per in %	capita in USD
1.	United States	26676	127.4	80958
2.	Japan	12139	244	96494
3.	China	7310	50	5214
4.	United Kingdom	3489	128.8	60890
5.	Italy	3055	162	51258
6.	France	3011	111	49039
7.	Germany	2928	76	35150
8.	Canada	1872	108	49263
9.	South Korea	762	47	14710
10.	Belgium	568	110	48966

Table 8: Public debt of selected countries of the world in 2020 (Roc, 2021).

No	Country	Debt volume in USD billion	Debt to GDP in %	Debt volume per capita in USD
1.	United States	52501	128	63551
2.	China	35558	67	10506
3.	Japan	19458	266	40263
4.	France	8948	116	42834
5.	United Kingdom	7541	95	47260
6.	Germany	6979	70	46171
7.	Canada	5265	118	45842
8.	Italy	5195	156	31644
9.	South Korea	3819	43	31737
10.	Spain	3737	120	27025

als, vegetation and other natural resources); material capital (the value of machinery, buildings and public establishments); human capital (the productive value of people); and social capital (the value of the family, community and the diverse organizations of society). Their use, in line with the challenges of civilization, was seen as essential to efforts to close the gap between rich and poor countries. Help was seen in generating economic growth on the subsoil of the idea of a knowledge-based economy.

Considering as an expression of the reproduction of material goods the indicator of the volume of domestic material consumption per capita (in tons), i.e. the total amount of materials consumed by the economy, which includes the sum of raw materials acquired by the economy on the national territory plus imports and minus exports of these raw materials, it should be noted, It is highest in Australia and Oceania, North America and Europe – with a tendency to decrease, which is the result of the introduction of modern techniques and technologies. The lowest level is in sub-Saharan Africa and South Asia, which reflects the far-reaching civilizational backwardness of countries in these regions.

The formation of reproductive processes is closely linked to economic growth in the subsoil of the national economy and economic relations with the international environment. These factors determine the economic activity of the country as well as the region and, consequently, the entire national economy. The most frequently cited synthetic measure of changes in economic activity, as well as the effects of the social reproduction process, is total and per capita GDP (table 9). If they showed an upward trend worldwide in the first two decades of the 21st century, they revealed a downward trend in the first half of the second decade in the group of countries changing the type of economy and in the countries of Australia and Oceania and Europe.

The outlined developmental tendencies of growth and economic development processes in individual regions of the world prove that in the modern world economy each type of social reproduction occurs. The dominant one in the analyzed period was expanded reproduction, with GDP increasing by more than 2.6 times. Key factors in this situation were the global exchange of knowledge and techniques and technology, international trade and capital flows.

Table 9: Volume of domestic material consumption per capita (tons) (Roc, 2021).

SPECIFICATION	2005	2010	2015	2017
WORLD	9.7	10.8	11.4	11.7
North Africa	6.3	9.1	7.4	7.8
Sub-Saharan Africa	4.1	4.3	4.1	4.1
Latin America and the Caribbean	9.3	10.2	10.3	10.6
North America	29.8	23.0	20.7	19.6
Australia and Oceania	33.0	29.8	28.6	28.0
Central Asia	11.5	12.6	13.7	14.1
South Asia	4.1	4.7	6.3	5.4
South-East Asia	7.0	8.3	8.0	8.3
East Asia	12.6	18.0	21.4	22.8
West Asia	10.5	13.0	13.9	14.4
Europe	14.5	13.2	13.1	13.1

Table 10: Total and per capita GDP (current prices) (Roc, 2021).

SPECIFICATION	2000	2010	2019
WORLD			
a. Total GDP in USD billion	33299	66010	87445
b. GDP per capita in USD	5436	9489	11339
Economically developed countries			
a. Total GDP in USD billion		41676	49824
b. GDP per capita in USD		41194	47149
Economically developing countries			
a. Total GDP in USD billion		22167	35141
b. GDP per capita in USD		3930	5545
Countries changing type of economy			
a. Total GDP in USD billion		2167	2479
b. GDP per capita in USD		7115	7862
Africa			
a. Total GDP in USD billion	647	1948	2461
b. GDP per capita in USD	796	1859	1884
Central and South America			
a. Total GDP in USD billion	2277	5340	5434
b. GDP per capita in USD	4321	8936	8309
North America			
a. Total GDP in USD billion	11029	16586	23185
b. GDP per capita in USD	35155	48365	62244
Australia and Oceania			
a. Total GDP in USD billion	478	1477	1639
b. GDP per capita in USD	1552	40627	39169
Asia			
a. Total GDP in USD billion	9281	20838	33082
b. GDP per capita in USD	2499	4968	7190
Europe			
a. Total GDP in USD billion	9588	19882	21645
b. GDP per capita in USD	13170	26824	28896

However, the process of social reproduction also came up against numerous constraints and barriers, generating significant areas of risk for it and consequently disrupting the continuous reproduction of material goods, labor and economic relations. In the first decades of the 21st century, their forced expression became processes of deindustrialization in rich countries, expressed in terms of a reduction in economic activity due to high labor costs, and processes of relocation of economic activity to developing countries due to lower labor costs, as well as attempts at processes of defeminization. Reducing these negative consequences has forced many countries, as well as regional groupings and international economic organizations, to undertake a number of strategies as well as economic policy measures. The nature of these depended largely on the economic system operating in the country in question (Lorenzi and Berrebi, 2018).

Another important problem affecting reproductive relations is the clash, besides economic interests and political-military conflicts, of the real interests of the various groups of the world community at the level of civilizational (cultural) conflict ("clash"). All of these together affect the world economic situation and, consequently, changes in economic activity, generating concrete and developmental repercussions (Huntington, 2001; Randers et al., 2014). This fact seems to be in line with earlier expectations formulated by many futurologists (A. and H. Toffler[16]). It is related to the fact that in the new world order that is taking shape, the growing awareness of the civilizational, national and religious affiliation of numerous peoples and nations is becoming increasingly apparent. Each of the known civilizations differs significantly from one another in many respects. They are united by different value systems, religions, worldviews, customs and social relations. They are also linked by territorial proximity and similarities in historical experience. The globalization processes leading to these changes have given traditional and global civilizations a corporate character (Kleer, 2019).

The cultural clash of 'civilizations' has also become apparent within the market economy, reverberating on issues such as economic growth and development, demographic growth, hunger and poverty, the environment, and the diseases afflicting global society. This underlines the assessment that no reforms can be carried out if the problem of culture is left to the margins of the solutions undertaken. Changes in

[16]Alvin Eugene Toffler (1928-2015) – American writer of Jewish origin, futurologist, author of works on the digital revolution, the communication revolution, the corporate revolution and the technological singularity.

Heidi Toffler (1929-2019) – futurologist, linguist, editor of works and co-author of the works of her husband A. F. Tofler.

this area require a profound cultural reorientation that strengthens the world community towards a different approach to nature and all the values of civilization. They should help to close the gap between the culture of the past and the culture of the present and future. Above all, the idea is not to reduce human beings only to the economic dimension, but more broadly to the institutional dimension (Robbins, 2008).

The above-mentioned background of civilizational (cultural) differences may give rise to dangerous phenomena – destructive ideologies that hierarchies people according to racial, national and religious affiliation. They generate chaos that must be perceived as an expression of civilizational overstimulation. The thesis that we are currently dealing with a period of replacement of the old civilization by a new one seems correct. The civilizational eclipse, however, is not a one-off and short-lived process. It gives rise to a number of turbulences inherent in the aspiration to impose one's position (one's ideas) through violence and expansion. It leads to a process full of contradictions in all spheres of society, including economic, social, political as well as cultural.

These contradictions are already apparent in the maturity of the civilizations being replaced – starting with the agrarian, industrial and informational civilizations to the hybrid one that is the sum of the best features of the previous ones. Its substrate in the global dimension is the dominant mode of economy, which is the market economy.

The civilization of the modern market economy is first and foremost a civilization of knowledge, referring to the idea of a knowledge-based economy, extensive social communication and visualization. The changes it brings relate to the expectations of the nature of the society of the future (A. Toffler) revealed by the overlapping waves of political, economic and systemic change – as brought about by the 1990s. In their subsoil, the construction of a new civilization began, bringing with it a new family style, social and economic life; a new awareness of people, their mutual relations and relation to each other; changes in the way they work; as well as new natural-climate, social and political-military conflicts (Toffler et al., 1995; Toeffler and Toeffler, 2006; Toffler, 2003).

The encroachment of the economy – both national, regional and global – into the areas of the new civilization varies from country to country as well as from region to region and from world to world. Existing religious denominations and churches have a significant influence on this situation. The structure of the world community – according to 2016 data – is dominated by Christians (comprising Catholics, Protestants and Orthodox Christians) - 32.9 percent; followed by Muslims – 23.6 percent; Hindus – 13.7 percent; Buddhists – 7 percent; followers of Chinese folk religions – 5.9 percent; followers of ethnic religions – 3.6 percent; followers of new religious movements – 0.9 percent: Sikhs – 0.3 percent; Jews – 0.2 percent; spiritualists – 0.2 percent; and irreligious – 11.1 percent (Roc, 2021). Each of the designated religious groups adheres to different values, customs and traditions. These also apply to the spheres of the economy. Among these, there are also fanatical movements with religious backgrounds in each of the religions operating on a global scale. They manifest themselves, albeit on a different scale, by dividing the world exclusively into good guys and bad guys.

Nationalism can also be an expression of the clash of civilizations. They are extreme expressions of the national (civilizational) consciousness of numerous peoples and nations, accompanied by an increase in national aspirations. Often nationalism finds support in a religious background.

An area of civilizational clash is also political pluralism – reflected in respect for democracy. Its spread means a systemic transformation for certain states and nations. It now covers significant areas of Europe (Central and Eastern) and Asia. However, experience in this area shows that it can take on the character of a 'sham', which in essence expresses a drive towards the consolidation of elites and the emergence of renewed authoritarian systems. This has to do with the fact that the process of systemic transformation itself does not contain in itself a tendency towards the consolidation of real democracy and is accompanied by various turbulences. It also means that, as such, it is fraught with many risks and dangers.

Closely linked to the political transformation is the change in the mode of economy, i.e., the expansion of the market economy sphere. This area is increasingly becoming an area of civilizational conflict. This is due to the nature of the market economy system, as it is not a model of closed national economies, but a model of an economy participating in an open international market. The phenomenon of the expanding sphere of the market economy is perceived and assessed differently. The prevailing opinion is that it is beneficial to overall development. It is also possible to perceive opinions that the development of the market system leads and will lead to the emergence of great dangers. With the introduction of the rules of the market economy, there are new challenges and problems to be solved (Ross, 2017).

An important area of the cultural clash of civilizations is the education of society and its effects. Its level creates numerous areas of barriers to the implementation of the knowledge economy on a global

scale. Its accessibility varies widely across the world. In developed countries, education systems cover the entire population of children and young people. By contrast, in a significant number of developing and underdeveloped countries, millions of children and young people do not have the opportunity to attend school. This situation is borne out by information on organized learning. The lowest levels globally are in Africa – especially Sub-Saharan Africa – and Central, South and West Asia. The highest levels are in Europe, Latin America and the Caribbean, Southeast and East Asia and North America.

A certain proportion of the world's population that has not participated in the education process forms an illiterate collective. In 2019, among the population, aged 15 years and over, the % of the population of given sex that could read was dominated by men (89.9%) over women (83.0%). The situation of male dominance over females also occurred for countries placed in the middle (males 90.1%; females 82.7%) and low development group (males 68.6%; females 53.5%) (Roc, 2021). High levels of illiteracy occur primarily in Africa. The main reason for this situation is primarily poverty, as a result of which African children in many countries have to work hard.

4 CONCLUSIONS

The reflections carried out, and on the basis of the paradigm of the new institutional economics, on the challenges facing the European community entitle us to formulate a number of reflections.

First. The output of the new institutional economics as an interdisciplinary science is proving useful for the identification, analysis and assessment of the challenges to civilization for the world community – including the European community. This is reflected in the growing range of analyses and interpretations of institutional economic phenomena. It remains a debatable issue, however, whether institutional analysis of socio-economic phenomena is to act as an alternative to the paradigm of mainstream economics, or whether it is to perform only a complementary or enriching function to the

Second. European society – like world society – subjected to the current of the greatest civilizational revolution taking place, is burdened by the spread of uncertainty, forcing a turn in thinking about the surrounding world. The imbalance in it confronts people with changes of a discontinuous nature, leading to overlapping changes in the economy and politics.

Third. Europe and its society being in the mainstream of the civilizational revolution reveal a better situation than the other continents in all the analyzed areas of civilizational challenges.

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Recurrence Measures of Complexity in Energy Market Dynamics

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Abstract: The instability of the price dynamics of the energy market from a theoretical point of view indicates the inadequacy of the dominant paradigm of the quantitative description of pricing processes, and from a practical point of view, it leads to abnormal shocks and crashes. Through the recurrence quantification analysis, we analyze and construct indicators of intermittent events in energy indices, where periods of regular behavior are replaced by periods of chaotic behavior, which could explain the emergence of crisis events. For further analysis, we have chosen daily data of Henry Hub natural gas spot prices, WTI spot prices, and Europe Brent spot prices. Our empirical results present that all of the presented recurrence measures respond in a particular way during crashes and can be effectively implemented for risk management strategies.

1 INTRODUCTION

Global economic and financial systems rely on crude oil to maintain stability, making it a strategic resource for national economic development (Zhang and Wu, 2019; Dong et al., 2018). The importance of examining various factors that may affect crude oil prices is therefore critical to investors, government agencies, and other stakeholders. Many factors contribute to crude oil price fluctuations, including fundamental factors (such as supply and demand of crude oil) (Wu and Zhang, 2014) and non-fundamental factors (such as speculations and investor sentiment) (Ji et al., 2019). Specifically, the global economic environment, political security between oil-producing countries and their neighbors, and economic policy uncertainty prove to have a significant impact on crude oil prices.

Regarding the strategic role of crude oil in economic progress, the market volatility of crude oil prices has had a substantial negative effect on the economy, specifically in those countries that are dependent on imports of crude oil. The impact of many drivers on crude oil price volatility has thus been investigated in a variety of publications, and crude oil market mechanism has become a controversial topic in academia (Coleman, 2012; Sari et al., 2011; Dées et al., 2007). While this was going on, some studies underlined the substantial risks associated with crude oil price changes, as well as their complexity and stochastic nature (Zhang and Wang, 2015; Shahzad et al., 2022; Yin and Wang, 2022; Zhang et al., 2023).

Oil prices are generally referred to as benchmark prices by both WTI and Brent contracts. Hedge funds and traders typically select one or the other contract. Consequently, there is considerable interest in the WTI-Brent pricing structure, including the shapes of the futures curves, the absolute price differences between the two benchmarks, and the degree of integration between the two markets. Hedge funds and financial institutions heavily trade these markets (directly and indirectly). As a result, the prices of jet fuel, heat-

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ing oil, diesel, and gasoline are highly influenced by these markets. The price spread between WTI and Brent is also used as the basis for a number of derivative financial products, such as swaps and options.

The microeconomic theory states that the supply and demand condition determines the fundamental value of crude oil price assets. The financialization of crude oil in the past decade, however, has increased the role of speculation in crude oil prices, making the process of determining crude oil prices more difficult (Kilian, 2009; Flood and Hodrick, 1990).

The natural gas industry has achieved strong growth in recent years because of the large demand market, sufficient low-cost supply, and active global natural gas trade. The forecasting of natural gas prices is one of the most crucial topics in finance since this resource is important for trading, electric power production planning, and regulatory decision-making. Nowadays, Henry Hub in the U.S., NBP in the U.K., and LNG in Japan represent major international trading centers of natural gas. These three centers have become an important reference point for determining the international level of natural gas prices. Among them, Henry Hub has the highest market liquidity, the largest influence, and the best reflection of the market supply and demand. On the other hand, in addition to the basic factors of supply and demand, the price of natural gas is driven by multiple factors such as extreme weather, wars, and geopolitics (Li et al., 2021).

Considering the highly nonlinear and non-stationary characteristics of crude oil and natural gas markets under the influence of complex factors, it is of great research significance to improve the accuracy of early identification of crisis phenomena in those markets. In this paper, we present indicators (indicators-precursors) based on recurrence analysis.

2 METHODOLOGY OF RECURRENCE ANALYSIS

In 1890 Poincaré introduced *Poincaré recurrence theorem* (Poincaré, 2017), which states that certain systems return to their arbitrarily close, or exactly the same initial states after a sufficiently long but finite time. Such property in the case of deterministic behavior of the system allows us to make conclusions regarding its future development.

2.1 Time Delay Method

The state of the system can be described by the set of variables. Its observational state can be expressed through a d-dimensional vector or matrix, where each of its components refers to a single variable that represents a property of the system. After a while, the variables change, resulting in different system states.

Usually, not all relevant variables can be captured from our observations. Often, only a single variable may be observed. *Thakens' theorem* (Takens, 1981) that was mentioned in previous sections ensures that it's possible to reconstruct the topological structure of the trajectory formed by the state vectors, as the data collected for this single variable contains information about the dynamics of the whole system.

For an approximate reconstruction of the original dynamics of the observed system, we project the time series onto a Reconstructed Phase Space (Eckmann and Ruelle, 1985; Kantz and Schreiber, 2003; Ott et al., 1994) with the commonly used time delay method (Kantz and Schreiber, 2003) which relied on the *embedding dimension* and *time delay*.

The embedding dimension is being the dimensionality of the reconstructed system (corresponds to the number of relevant variables that may differ from one system to another. The time delay parameter specifies the temporal components of the vector components.

2.2 Recurrence Plot

Recurrence plot (RP) have been introduced to study dynamics and recurrence states of complex systems. When we create RP, at first, from recorded time series we reconstruct phase-space trajectory. Then, according to Eckmann et al. (Eckmann et al., 1987), we consider a trajectory $\vec{\mathrm{X}}(i)$ on the reconstructed trajectory. The recurrence plot is an array of dots in a $N \times N$ matrix, where dot is placed at (i, j) whenever $\vec{\mathrm{X}}(j)$ is sufficiently close to $\vec{\mathrm{X}}(i)$, and both axes are time axes which mathematically can be expressed as

$$R_{ij} = \Theta(\varepsilon - \left\| \vec{\mathrm{X}}(i) - \vec{\mathrm{X}}(j) \right\|), \quad \text{for } i, j = 1, \ldots, N, \tag{1}$$

where $\| \, \|$ is a norm (representing the spatial distance between the states at times i and j); ε is a predefined recurrence threshold, and $\Theta(\cdot)$ is the Heaviside function. As a result, the matrix captures a total of N^2 binary similarity values.

Typically, L_p-norm is applied to determine the pairwise similarity between two vectors. According to Webber and Zbilut (Webber and Zbilut, 2005), the L_1-norm (Taxicab metric), the L_2-norm (Euclidean metric), and the L_∞-norm (Chebyshev metric) can serve as candidates for measuring distance between trajectories in phase space.

Also, as it can be seen from equation (1), the similarity between vectors is determined by a threshold

ε. The choice of $\varepsilon > 0$ ensures that all vectors that lie within this radius are similar to each other, and that dissimilarity up to a certain error is permitted (Poincaré, 2017).

The fixed radius for recurrent states is the commonly used condition, which leads to equally sized ε-neighborhoods. The shape in which neighborhoods lie is determined by the distance metric. Applying the fixed threshold with the distance metric, we define recurrence matrices that are symmetric along the middle diagonal. The self-similarity of the multi-dimensional vectors reflects in the middle diagonal, which is commonly referred to as the line of identity (LOI). In contrast, it is not guaranteed that a recurrence matrix is symmetric if the condition of the fixed number of nearest neighbors is applied. For specific purposes (e.g., quantification of recurrences), it can be useful to exclude the LOI from the RP, as the trivial recurrence of a state with itself might not be of interest (Charles et al., 2015).

2.2.1 Recurrence Plots and their Structures

The main purpose of RP is the visualization of trajectories and hidden patterns of the systems (Marwan et al., 2007; Charles et al., 2015).

The dots within RP, representing the time evolution of the trajectories, exhibit characteristic large-scale and small-scale patterns. Large-scale patterns of RP can be classified as

- *homogeneous* – autonomous and stationary systems, which consist of many recurrence points that are homogeneously distributed (relaxation times are short);
- *periodic* – long, uninterrupted, and diagonally oriented structures that represent which indicate periodic behavior. These lines are usually distributed regularly;
- *drift* – systems with patterns paling or darkening from the LOI to the outer corners of RP;
- *disrupted* – systems with drastic changes as well as extreme events in the system dynamics.

The small-scale clusters can represent a combination of *isolated dots* (abrupt events). Similar evolution at different periods in time or in reverse temporal order will present *diagonal lines* (deterministic structures) as well as *vertical/horizontal lines* to inscribe laminar states (intermittency) or systems that paused at singularities. For the quantitative description of the system, such small-scale clusters serve the base of the *recurrence quantification analysis* (RQA).

2.3 Recurrence Quantification Analysis

The graphic representation of the system suits perfectly for a qualitative description. However, the main disadvantage of graphical representation is that it forces users to subjectively intuit and interpret patterns and structures presented within the recurrence plot. Also, with the increasing size of RP, they can be hardly depicted on graphical display as a whole. As a result, we need to work with separated parts of the original plot. Analysis in such a way may create new defects, which should distort objectivity of the observed patterns and lead to incorrect interpretations. To overcome such limitation and spread an objective assessment among observers, in the early 1990s by Webber and Zbilut (Webber and Zbilut, 1994; Zbilut and Webber, 1992) were introduced definitions and procedures to quantify RP's complexity, and later, it has been extended by Marwan et al. (Marwan et al., 2002).

The first known measure of the RQA is *recurrence rate*, which measures the probability that the studied process will recur (*RR*):

$$RR = \frac{1}{N^2} \sum_{i,j=1}^{N} R_{i,j}. \tag{2}$$

Another measure is based on frequency distribution of line structures in the RP. First, we consider the histogram of the length of the diagonal structures in the RP

$$\begin{aligned} P(l) = &\sum_{i,j=1}^{N} (1 - R_{i-1,j-1}) \\ &\times (1 - R_{i+l,j+l}) \prod_{k=0}^{l-1} R_{i+k,j+k}. \end{aligned} \tag{3}$$

The percentage of recurrence points that form diagonal segments of minimal length l_{min} parallel to the main diagonal is the measure of *determinism* (*DET*):

$$DET = \sum_{l=l_{min}}^{N} lP(l) \Big/ \sum_{l=1}^{N} lP(l). \tag{4}$$

Systems that are characterized by long diagonal lines are presented to be periodic. From chaotic signals, we would expect short diagonal lines, and stochastic processes would not present any diagonal lines. Performing the RQA, typically, we rely on the lines with minimal length, which excludes the shorter lines, which may be spurious for characterizing deterministic processes. In our case, $l_{min} = 2$ is considered. In case when $l_{min} = 1$, DET and RR are identical.

Considering diagonal line segments, we can emphasize the longest one – L_{max}. This indicator measures the maximum time that two trajectories remain

close to each other and can be interpreted as the maximum prediction time:

$$L_{max} = \max\left(\{l_i \,|\, i = 1,\ldots,N_l\}\right), \tag{5}$$

where $N_l = \sum_{l \geqslant l_{min}} P(l)$ is the total number of diagonal lines.

Divergence (DIV) is the inverse of L_{max} characterizes the exponential divergence of the phase space trajectory (Goldberger et al., 2000; Kirchner et al., 2014):

$$DIV = 1 \Big/ L_{max}. \tag{6}$$

For longer diagonal lines system is more deterministic and, therefore, the measure of divergence is also lower. The smaller L_{max}, the more divergent are trajectories and more chaotic the studied system. According to Eckmann et al. (Eckmann et al., 1987), DIV can be used to estimate the largest positive Lyapunov exponent.

Another measure which is related to the diagonal line segments is the *average diagonal line length* (L_{mean}):

$$L_{mean} = \sum_{l=l_{min}}^{N} lP(l) \Big/ \sum_{l=l_{min}}^{N} P(l) \tag{7}$$

It can be interpreted as the mean prediction horizon of the system, and it measures average time that two trajectories remain close to each other.

Using the classic Shannon entropy, we can measure the hidden complexity of recurrence structures in the RP. In accordance with this study, the entropy of diagonal line histogram ($DLEn$) is of the greatest interest. It can be defined as:

$$DLEn = -\sum_{l=l_{min}}^{N} p(l) \ln p(l) \tag{8}$$

and

$$p(l) = P(l) \Big/ \sum_{l=l_{min}}^{N} P(l), \tag{9}$$

where $p(l)$ captures the probability that a diagonal line has exactly length l, and $DLEn$ reflects the complexity of deterministic structure in the system. The more uniform is the frequency distribution of diagonal lines, the higher the value of $DLEn$. If there is predominant deterministic behavior with a particular period l, then $DLEn$ becomes lower.

As it was mentioned, the RP structure consists of vertical (horizontal lines). For them Marwan and Webber (Marwan and Webber, 2015) proposed additional recurrence measures. The first of them is the *laminarity* (LAM) Analogously to the equation (4), which measures the percentage of diagonal lines with minimal length l_{min} in the RP, we can calculate the fraction of recurrence points forming vertical structures of minimal length v_{min}:

$$LAM = \sum_{v=v_{min}}^{N} vP(v) \Big/ \sum_{v=1}^{N} vP(v) \tag{10}$$

with

$$\begin{aligned} P(v) = &\sum_{i,j=1}^{N} (1 - R_{i,j-1}) \\ &\times (1 - R_{i,j+v}) \prod_{k=0}^{v-1} R_{i,j+k} \end{aligned} \tag{11}$$

as the histogram of lengths of vertical lines.

Since it measures the overall amount of vertical lines, it characterizes the percentage of laminar states within the system. If LAM increases, then there are more vertical or diagonal structures than isolated recurrent points.

Similarly to L_{max}, we can define the measure which will indicate the maximum time that a system holds an unchangeable pattern – the *maximal vertical lines length* (V_{max}):

$$V_{max} = \max\left(\{v_i \,|\, i = 1,\ldots,N_v\}\right), \tag{12}$$

where $N_v = \sum_{v \geqslant v_{min}} P(v)$ is the total number of vertical lines.

Vertical line divergence ($VDIV$) is the analogous to (6), which can be related to the rate of divergence from laminar state:

$$VDIV = 1 \Big/ V_{max}. \tag{13}$$

Consequently, we can define the average time that two trajectories remain at a specific state – *trapping time* (TT):

$$TT = \sum_{v=v_{min}}^{N} vP(v) \Big/ \sum_{v=v_{min}}^{N} P(v). \tag{14}$$

For high TT values we would expect the system to consist of more laminar states, whereas low TT values would indicate abrupt changes in the system's dynamics.

The variability of laminar states with different duration time can be measured in the same way as for diagonal lines – using Shannon entropy. The complexity of vertical lines can be measures according to the following equation:

$$VLEn = -\sum_{v=v_{min}}^{N} p(v) \ln p(v) \tag{15}$$

with

$$p(v) = P(v) \Big/ \sum_{v=v_{min}}^{N} P(v) \tag{16}$$

indicating the probability of a vertical line to have length $v \geqslant v_{min}$.

In the same manner, we can quantify the variation (complexity) of abrupt changes during the studied periods in the energy markets. Regarding equation (7), we can quantify the average time of divergence when two trajectories in the phase-space remain out of recurrence threshold ε. This measure can be called as *average white vertical line length* (WVL_{mean}):

$$WVL_{mean} = \sum_{w=w_{min}}^{N} wP(w) \Big/ \sum_{w=w_{min}}^{N} P(w), \qquad (17)$$

where $P(w)$ is the frequency of white vertical lines in the RP. This measure can be interpreted as the mean horizon of unpredictability of the system.

This kind of complexity is associated with the white vertical lines in the RP and can be quantified in the following way:

$$WVLEn = -\sum_{w=w_{min}}^{N} p(w) \ln p(w) \qquad (18)$$

with

$$p(w) = P(w) \Big/ \sum_{w=w_{min}}^{N} P(w) \qquad (19)$$

indicating the probability of a white vertical line to have length $w \geqslant w_{min}$.

The further measure is based on the ration between DET and RR, and known as *ratio* (DET/RR):

$$DET/RR = N^2 \sum_{l=l_{min}} P(l) \Big/ \left(\sum_{l=1}^{N} lP(l) \right)^2 \qquad (20)$$

In the same manner, we can define another measure which is based on the ratio between LAM and DET:

$$LAM/DET = \sum_{v=v_{min}}^{N} vP(v) \cdot \sum_{l=1}^{N} lP(l) \Big/ \sum_{v=1}^{N} vP(v) \cdot \sum_{l=l_{min}}^{N} lP(l). \qquad (21)$$

This measures can be used to uncover hidden transitions in the dynamics of the system (Webber and Zbilut, 1994).

3 RESULTS AND ANALYSIS

Regarding previous studies, we present additional analysis on co-movement between 3 energy-related indices and construct indicators or indicators-precursors based on the using recurrence analysis.

The presented work uses daily data of Henry Hub natural gas spot prices (US$/MMBTU) ranged from 7 February 1997 to 18 October 2022; Cushing, OK WTI spot prices FOB (US$/BBL) ranged from 20 May 1987 to 17 October 2022; Europe Brent spot prices FOB (US$/BBL) ranged from 20 May 1987 to 17 October 2022 (U.S. Energy Information Administration, 1997, 1986).

In figure 1 are presented:

- the dynamics of the initial time series;
- standardized returns, where returns can be calculated as $G(t) = [x(t+\Delta t) - x(t)]/x(t)$ and their standardized version as $g(t) = [G(t) - \langle G \rangle]/\sigma$;
- probability density function of the standardized returns.

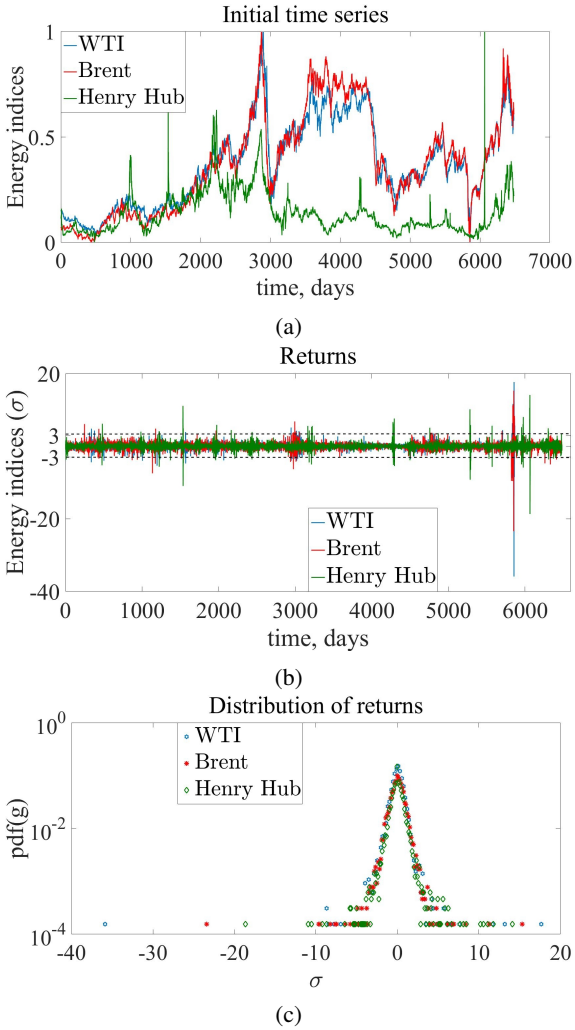


Figure 1: Initial time series (a), standardized returns (b), and pdf of standardized returns of WTI spot prices (WTI), Europe Brent spot prices (Brent), and Henry Hub natural gas spot prices (Henry Hub).

We can see that most periods in energy markets are defined by events that exceed $\pm 3\sigma$. Both WTI and Brent returns are characterized by much more extensive crashes. Previous studies pointed out that such events are located in fat-tails of the probability distribution. Such crashes are the main source of high complexity and non-linearity in the studied systems.

Most of our results are based on the sliding window approach. The idea here is to take a sub-window of a predefined length w. For that sub-window, we perform recurrence quantification analysis, get necessary indicators that are appended to the array. Then, the window is shifted by a predefined time step h, and the procedure is repeated until the time series is completely exhausted.

We have performed RQA under sliding window procedure for standardized returns and standardized initial time series (Soloviev et al., 2020; Bielinskyi and Soloviev, 2018; Bielinskyi et al., 2022, 2021c,b, 2020). We have found that standardized initial time series better expresses internal complexity and recurrent properties of the energy market indices.

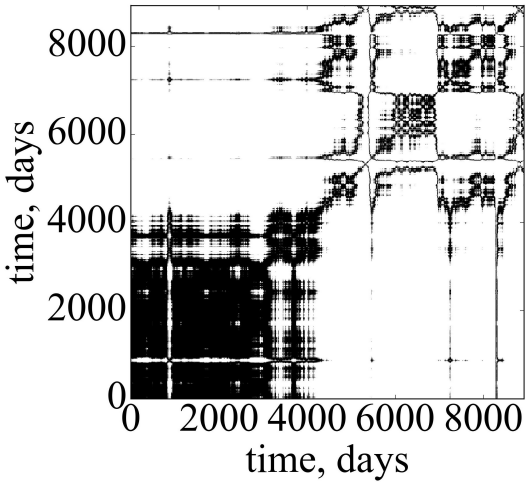
RQA was performed for the following parameters:

- embedding dimension $d_E = 1$;
- time delay $\tau = 1$;
- recurrence threshold $\varepsilon = 0.3$;
- L_2-norm as a candidate for measuring distance between trajectories in phase space;
- minimum diagonal line length $l_{min=2}$;
- minimum vertical line length $v_{min} = 2$;
- minimum white vertical line length $w_{min} = 2$;
- sliding window length $w = 500$ days;
- sliding window time step $h = 1$ day.

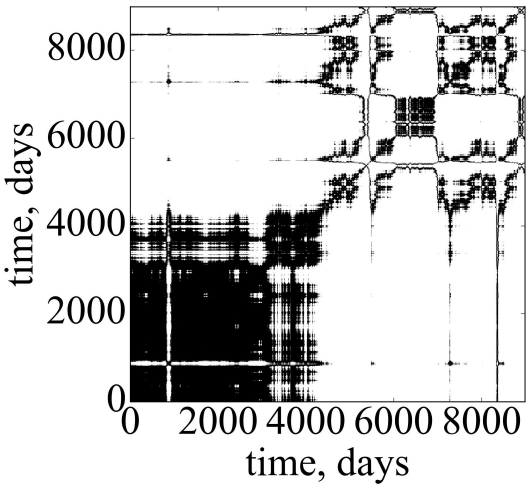
Worth to mention that the experiments were performed for sliding window lengths of 250 days and 500 days. We have chosen the second option since it represents a more reliable and smoother dynamics of all the presented indicators. All described measures result into highly volatile variation with the sliding window of 250 days that difficult to interpret.

In figure 2 are presented RPs for the studied series.

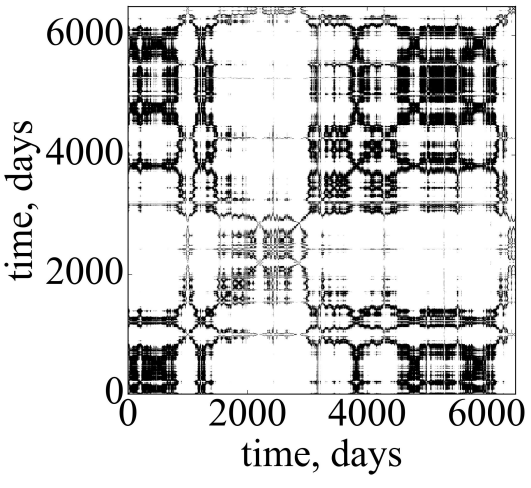
Recurrence plots in figure 2 represent that the studied energy markets are highly inhomogeneous. As it was expected, nonlinear structure of WTI and Brent is presented to be very similar, comparing to Henry Hub. Recurrence structure of all indices varies across time. They do not follow a certain pattern, presented to be non-periodic, and there are differences in the patterns that concern the frequency of their appearance, shape, and size. It should be noticed that for the oil markets first 4000 days are presented to be



(a)



(b)



(c)

Figure 2: Recurrence plots calculated for WTI (a), Brent (b), and Henry Hub (c) standardized time series.

highly recurrent, while the remaining days seem to be more volatile, which is indicated by high proportion of white regions. The recurrence structure of Henry Hub index is presented to be more uniformly distributed. The variations of recurrence patterns should be more noticeable during crashes. Recurrence quantitative indicators should give a more accurate representation of the complex, chaotic structure of the studied markets.

Figure 3 represents recurrence measures of determinism (DET) and laminarity (LAM).

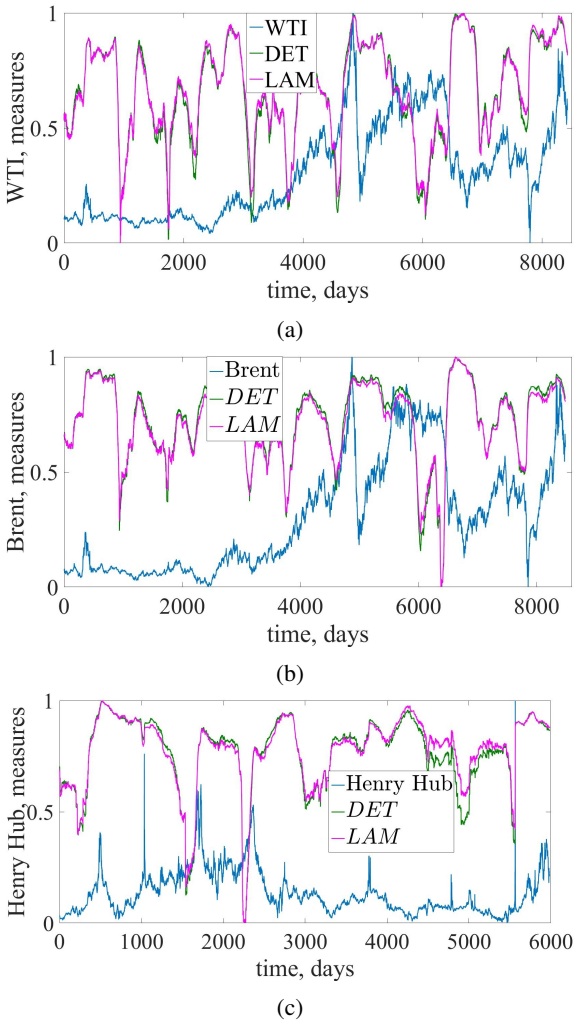


Figure 3: Recurrence measures of determinism (DET) and laminarity (LAM) calculated for WTI (a), Europe Brent (b), and Henry Hub (c) indices.

In figure 3 we see that DET and LAM increase during crisis events of all markets. We may conclude that those critical states are characterized by high degree of laminarity and determinism. Crashes are presented to be highly complex and deterministic. Their degree of predictability becomes higher, and corresponding recurrence measures seem to be indicators or even indicators-precursors of such changes.

Figure 4 represents recurrence measures of ratios DET/RR and LAM/DET.

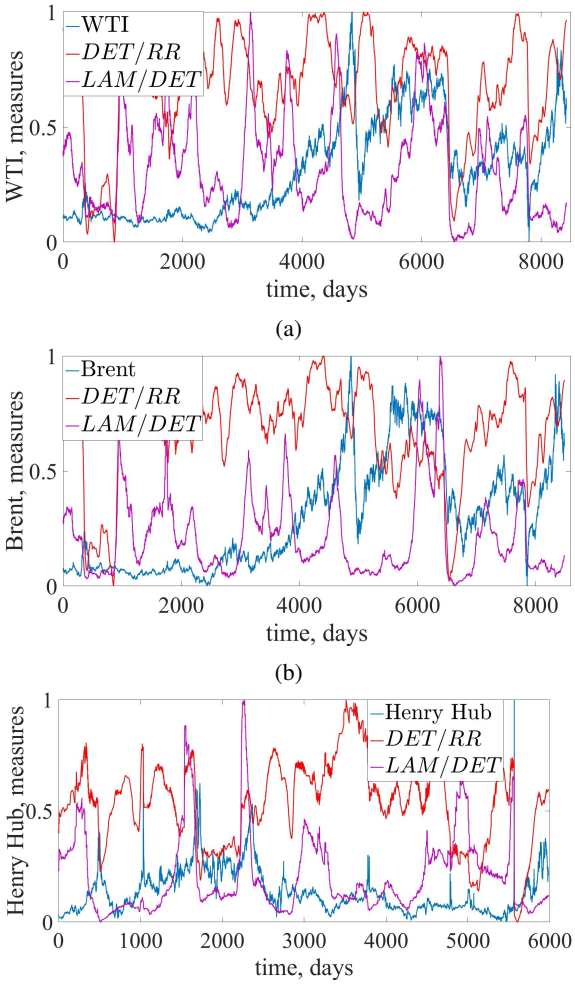


Figure 4: Recurrence measures (DET/RR) and (LAM/DET) calculated for WTI (a), Europe Brent (b), and Henry Hub (c) indices.

From figure 4 we can see that both measures decrease during crisis events of energy indices. For ratio DET/RR we may say that the overall percentage of recurrence points in RP becomes higher than the percentage of only diagonal structures in RP. For ratio LAM/DET we see precisely the same behavior during crashes, i.e., it starts to decline during crisis or even in advance. Thus, it can be seen that the overall determinism of the system during crashes is much higher than the degree of laminarity.

Figure 5 shows recurrence measures of diagonal

(DIV) and vertical line ($VDIV$) divergences.

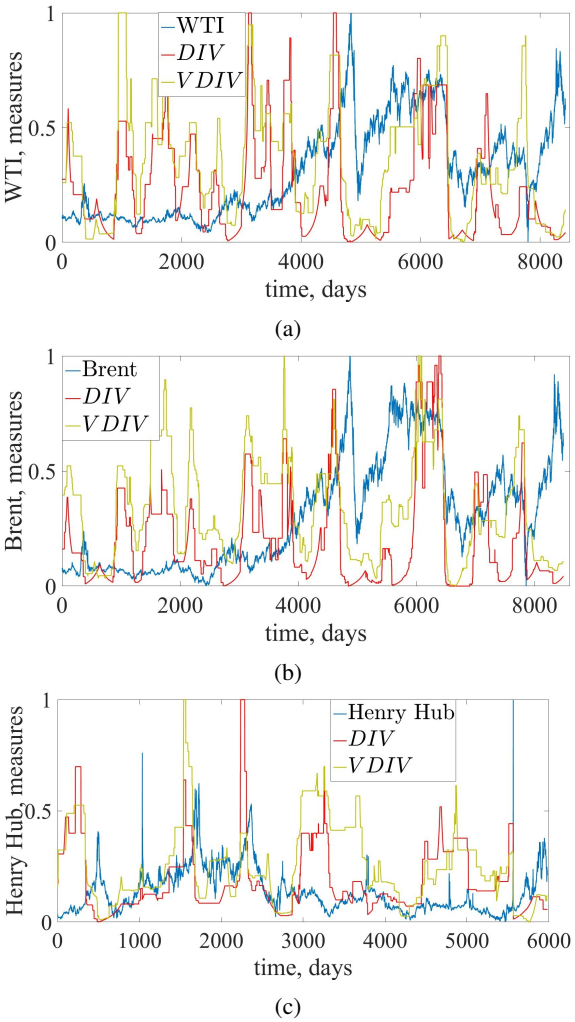


Figure 5: Recurrence measures of diagonal line divergence (DIV) and vertical line divergence ($VDIV$) calculated for WTI (a), Europe Brent (b), and Henry Hub (c) indices.

Figure 5 demonstrates that the divergence of deterministic and laminar structure of energy-related markets becomes lower during critical states. Since both measures are inverse quantities to maximum diagonal and vertical line length (L_{max} and V_{max}), such behavior has to be obvious. Previous measures have made it clear to us that the crisis phenomena of energy indices are characterized by a high degree of determinism and laminarity. In this case, the lengths of diagonal and vertical lines should also increase, which indicate an increase in the horizon of predictability and immutability.

Figure 6 represents recurrence measures of recurrence rate (RR), average diagonal line length (L_{mean}), and trapping time (TT).

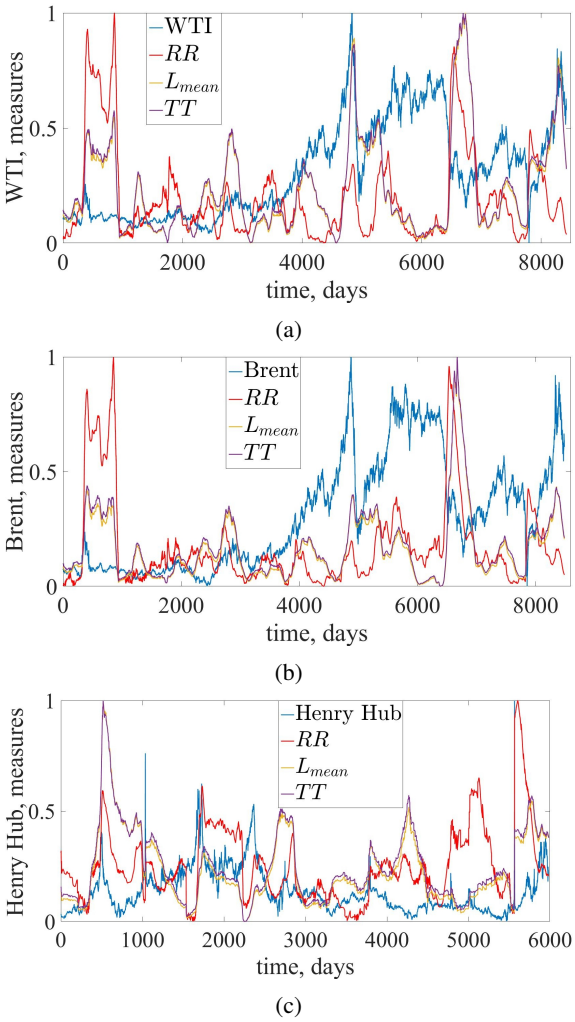


Figure 6: Recurrence measures of recurrence rate (RR), average diagonal line length (L_{mean}), and trapping time (TT) calculated for WTI (a), Europe Brent (b), and Henry Hub (c) indices.

In figure 6 we see that recurrence rate increases during crisis phenomena. This means that the total number of trajectories in the phase space that are close enough to each other becomes larger on the eve of a crisis or at the moment of its onset. Thus, the probability of recurrence state increases during crash. Regarding previous measures, RR and L_{mean}, we see that the average degree of predictability during crisis increases. The same can be seen for trapping time: average degree of changeability increases during crashes. Based on this indicator, we may conclude that the system is 'trapped' in a state of crisis.

Figure 7 presents recurrence measures of average white vertical line length (WVL_{mean}), and diagonal, vertical and white vertical line entropies ($DLEn$, $VLEn$, and $WVLEn$).

From figure 7 we can see that all the presented

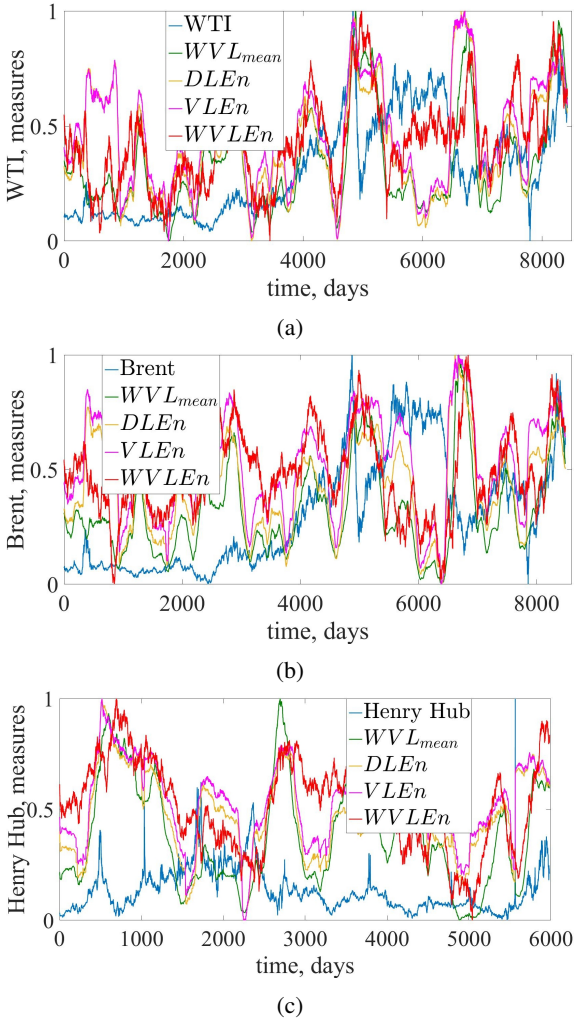


Figure 7: Recurrence measures of average white vertical line length (WVL_{mean}), diagonal line entropy ($DLEn$), vertical line entropy ($VLEn$), and white vertical line entropy ($WVLEn$) calculated for WTI (a), Europe Brent (b), and Henry Hub (c) indices.

quantitative measures of recurrence begin to increase during crises, indicating a special state of the market at these points in time. The average white vertical line length shows that crisis events are characterized not only by the determinism of the dynamics of market movement, but also by the dissimilarity of these events to many previous ones, since the length of the white vertical lines is becoming an increasing trend. It can also be said that the market represents a much more deterministic structure than a laminar one. Also, the degree of volatility of these events can knock the market dynamics out of the limits of the epsilon value.

The diagonal line entropy also shows an increasing trend. Since the Shannon entropy is maximal with a uniform distribution, it can be concluded that the collapse events of energy indices are characterized by different horizons of predictability. That is, in the pre-crisis dynamics there is no black diagonal line of the same length, which is the dominant one. During a crisis, horizons of determinism appear, which gain even more weight if compared with the rest.

The vertical line entropy increases similarly to $DLEn$. We may assume that similarly to diagonal lines laminar states have different horizons of invariability during crash events, and these horizons of invariability have greater tendency to uniform distribution.

The white vertical line entropy increases similarly to other entropies. This dynamics is consistent with the WVL_{mean} measure.

4 CONCLUSIONS

In this paper, we have studied highly nonlinear and nonstationary dynamics of oil and gas markets from the perspective of the recurrence analysis. Taking into account daily data of Henry Hub natural gas spot prices from 7 February 1997 to 18 October 2022, WTI spot prices from 20 May 1987 to 17 October 2022, and Europe Brent spot prices for the same period as WTI, we have drown some conclusions from the empirical results.

Firstly, recurrence plots presented that the studied markets demonstrate highly inhomogeneous. As it was expected, nonlinear structure of WTI and Brent is presented to be very similar, comparing to Henry Hub. Recurrence structure of all indices varies across time. They do not follow a certain pattern, and there are differences in frequency, shape, and size of black- and white-dot patterns that appear across time.

From quantitative measures of complexity, we have drawn the following conclusions:

1. Crash events of energy-related indices are characterized by high degree of laminarity and determinism. Crashes are presented to be highly complex and deterministic.
2. The overall percentage of recurrence points in RP becomes higher than the percentage of only diagonal structures in RP. At the same time, the percentage of diagonal lines in RP during crises is much higher than the percentage of vertical lines. Thus, the overall degree of determinism is larger than laminarity.
3. The divergence of deterministic and laminar structure of WTI, Brent, and Henry Hub becomes lower during critical states that indicate higher degree of repeatability in the dynamics of the studied systems. Also, it gives understanding that

the phase-space trajectories become close to each other during critical phenomena of financial systems.

4. Such measures as recurrence rate, mean diagonal line length, and trapping time also increase during crisis phenomena. This means that the total number of trajectories in the phase space that are close enough to each other becomes larger before or during crash. Therefore, the probability of recurrence state increases, and the average degree of predictability becomes higher. A larger portion of vertical lines indicates that the system is 'trapped' in a state of crisis for a particular period of time.
5. Entropy-based measures and, particularly, white vertical line measures show that energy-related indices represent complex nonlinear patterns that combine not only horizons of determinism and laminarity, but also some dissimilarity patterns reflected into white lines.

The applied approach to WTI, Brent, and Henry Hub indices approve that the energy market is an open, highly complex, chaotic, and nonlinear system that depends on different technical and fundamental factors. Although RPs and RQA give promising results for crisis prediction and the construction of early-warning indicators, it needs further development to give applicable trading strategies relying on recurrence indicators and further development of autonomous trading bots.

Also, since the proposed recurrence measures are only indicators (indicators-precursors) that give the possibility to monitor crisis phenomena at a particular moment of the market's existence, forecasting of such events requires integration of the proposed indicators with the particular forecasting models (Yin and Wang, 2022; Fang et al., 2023; Li et al., 2021; Zhang et al., 2023; Zou et al., 2023; Guliyev and Mustafayev, 2022; Kiv et al., 2021). It seems a promising direction at the junction of artificial intelligence and fuzzy logic methods (Bielinskyi et al., 2021a; Bondarenko, 2021; Kmytiuk and Majore, 2021; Kobets and Novak, 2021; Kucherova et al., 2021; Lukianenko and Strelchenko, 2021; Miroshnychenko et al., 2021).

At the same time, we intend to investigate cross-recurrences between energy indices and different technical and fundamental indicators using such approaches as cross- and joint-recurrence quantification analysis (Ashe and Egan, 2023; He and Huang, 2020; Romano et al., 2004).

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High-Order Networks and Stock Market Crashes

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Keywords: High-Order Network, Crash, Complex networks, Multiplex Networks, Visibility Graph, Indicator-Precursor.

Abstract: Network analysis has proven to be a powerful method to characterize complexity in socio-economic systems, and to understand their underlying dynamical features. Here, we propose to characterize the temporal evolution of higher-order dependencies within the framework of high-order networks. We test the possibility of financial crashes identification on the example of the Dow Jones Industrial Average (DJIA) index. Regarding topological measures of complexity, we see drastic changes in the complexity of the system during crisis events. Using high-order network analysis and topology, we show that, unlike traditional tools, the presented method is the most perspective, comparing to traditional methods of financial time series analysis.

1 INTRODUCTION

The growing availability of extensive data, often with time resolution, and coming from very different complex systems, has led to the possibility of a detailed study of their behavior, and in some cases also their internal mechanisms. Complex systems of various nature (biological, technical, financial, economic, etc. (Barabási and Pósfai, 2016; Latora et al., 2017) consist of numerous elementary units that interact heterogeneously with each other and in almost all cases exhibit emergent properties at the macroscopic level. Complex networks have become a powerful basis for studying the structure and dynamics of such systems (Newman, 2010). However, despite notable successes, their tools are limited to describing interactions between two units (or nodes) at the same time, which clearly contradicts the growing empirical data on group interactions in many cases of heterogeneous systems (Battiston and Petri, 2022). It turns out that connections and relationships take place not only between pairs of nodes, but also as collective actions of groups of nodes (Battiston et al., 2021; Sun and Bianconi, 2021), having a significant impact on the dynamics of interacting systems (Battiston et al., 2020; Majhi et al., 2022).

The idea of higher-order interactions is well known in the framework of solid-state physics when the approximation of paired interactions was replaced by multiparticle potentials or quantum mechanical calculations. Or in thermodynamics and statistical physics, Tsallis' efforts have built a theory of nonextensive interactions (Lyra and Tsallis, 1998; Bielinskyi et al., 2022). However, in all these cases, representations of higher-order interactions are simple in the sense that they do not contribute to the emerging complexity of the problem. In complex systems, usually described as networks, the situation is different, and in many cases these interactions need to be taken into account using more complex mathematical structures, such as hypergraphs and simplicial complexes.

To date, various models of higher-order networks have been developed (Bobrowski and Krioukov, 2022), the number of which, including modifications, is growing rapidly, given the relevance and topicality of the study. Let's briefly consider the main

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models that have shown themselves positively (Benson et al., 2018; Bick et al., 2021; Lambiotte et al., 2019).

Multiplex Networks. Multiplex, multilayering, and networks of networks have been proposed as modeling paradigms for systems in which there are different types of interactions (Boccaletti et al., 2014). They are designed to account for links of different types. However, in most cases, interactions are dyadic in nature and therefore can be represented by traditional networks (Skardal et al., 2021). The use of multiplex networks for financial analysis tasks is described in detail in (Bardoscia et al., 2021; del Rio-Chanona et al., 2020; Serguieva, 2016; Brummitt and Kobayashi, 2015; Cao et al., 2021; Xie et al., 2022; Gao, 2022; Aldasoro and Alves, 2018; Squartini et al., 2018; del Rio-Chanona et al., 2020), and higher-order networks in (Stavroglou et al., 2019; Jackson and Pernoud, 2021; Saha et al., 2022; Battiston et al., 2016; Huremovic et al., 2020; Franch et al., 2022; Bartesaghi et al., 2022; Han et al., 2022).

Hypergraphs and Simplicial Complexes. Computational methods from algebraic topology, hypergraphs, and simplicial complexes, which are sets of nodes and hyperlinks, allow encoding any number of units to explicitly consider systems beyond pairwise interactions and extract any "shape" of the data (Battiston et al., 2020; Santoro et al., 2022; Battiston et al., 2021; Berge, 1976).

Higher-order Markov Models for Sequential Data. Markov models defined in networks have become a popular way to describe and model the flows of information, energy, mass, money, etc. between various objects. If evolution is given by a Markov process (of the first order), this process can be considered as a random walk through the graph (Masuda et al., 2017). However, many empirically observed flows in networks have some dependence on the path. Thus, higher-order Markov chain models are required (Lambiotte et al., 2019).

Higher-order graphical Models and Markov Random Fields. Markov random fields, such as the Ising model and more general graphical models, have also been extended to higher-order models that take into account the interaction between several objects (Shemesh et al., 2013; Komodakis and Paragios, 2009).

Finally, more recently, Santoro et al. (Santoro et al., 2022) proposed a new structure for characterizing instantaneous patterns of signal co-fluctuation of all orders of interaction (pairs, triangles, etc.). To study the global topology of such co-fluctuations, they combined time series analysis, the theory of complex networks, and the analysis of topological data (Wasserman, 2018). They were able to show that, unlike traditional time series analysis tools, higher-order measures are able to reveal the subtleties of different space-time regimes in the case of three different studies: brain activity at rest (measured by fMRI data), stock option prices, and epidemic tasks.

In this paper, we consider the possibility of applying multiplex and higher-order network techniques to modeling crisis states in the stock market. Section 2 presents a graph representation of time series based on the classically paired visibility – visibility graph. Section 3 presents the theory of multiplex networks, which makes it possible to study systems of subgraphs (layers) and their inter- and intra-layer connections. Measures based on them are also provided. Section 4 describes high-order network extensions, various approaches to encoding high-order connections, and measures that will be used for both classical and high-order networks. Section 5 presents empirical results, together with which a comparative analysis of measures based on classical networks, multiplex, and higher-order networks is carried out. Section 6 presents the conclusions of the work done and further prospects.

2 VISIBILITY GRAPH

Visibility graph (VG), which was proposed by Lacasa et al. (Lacasa et al., 2008) is typically constructed from a univariate time series. In a visibility graph, each moment in the time series maps to a node in the network, and an edge exists between the nodes if they satisfy a "mutual visibility" condition.

"Mutual visibility" can be understood by imagining two points x_i at time t_i and x_j at time t_j as two hills of a time series, which can be understood as a landscape, and these two points are "mutually visible" if x_i has no any obstacles in the way on x_j. Formally, two points are mutually visible if, all values of x_k between t_i and t_j satisfy:

$$x_k < x_i + \frac{t_k - t_i}{t_j - t_i}\left[x_j - x_i\right], \quad \forall k : i < k < j \qquad (1)$$

Horizontal visibility graph (HVG) (Luque et al., 2009) is a restriction of usual visibility graph, where two points x_i and x_j are connected if there can be drawn a *horizontal* path that does not intersect an intermediate point x_k, $i < k < j$. Equivalently, node x_i at time t_i and node x_j at time t_j are connected if the horizontal ordering criterion is fulfilled:

$$x_k < \inf(x_i, x_j), \quad \forall k : i < k < j. \qquad (2)$$

Figure 1 is an approximate illustration of the construction of visibility graphs.

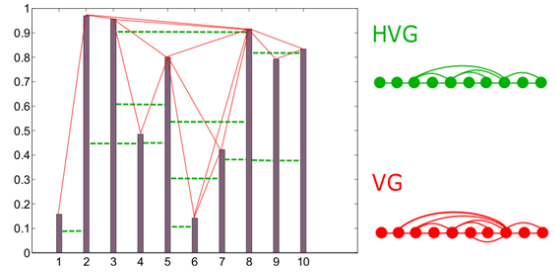

Figure 1: Schematic illustration of the VG (red lines) and the HVG (green lines). Adapted from (Iacovacci and Lacasa, 2016).

3 MULTIPLEX ORDERNESS AND MEASURES OF COMPLEXITY

Multiplex network (Kivelä et al., 2014) is the representation of the system which consists of the variety of different subnetworks with inter-network connections. For working with multiplex financial networks, we set two tasks:

- convert separated time series into network that represent a layer of a multiplex network. The procedure of conversion is presented in section 2;
- create intra-layer connection between each subnetwork.

Figure 2 represents an algorithm for creating a three-layered multiplex visibility graph.

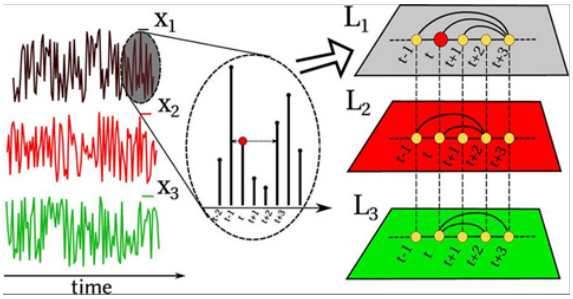

Figure 2: Illustration of the multiplex VG formation on the example of three layers. Adapted from (Lacasa et al., 2015).

Multiplex network is the representation of a pair $M = (G,C)$, where $\{G_\alpha \,|\, \alpha \in 1,\ldots,M\}$ is a set of graphs $G_\alpha = (X_\alpha, E_\alpha)$ that called layers and

$$C = \left\{E_{\alpha\beta} \subseteq X_\alpha \times X_\beta \,|\, \alpha,\beta \in 1,\ldots,M, \alpha \neq \beta\right\} \quad (3)$$

is a set of intra-links in layers G_α and G_β ($\alpha \neq \beta$). E_α is intra-layer edge in M, and each $E_{\alpha\beta}$ is denoted as inter-layer edge.

A set of nodes in a layer G_α is denoted as $X_\alpha = \{x_1^\alpha,\ldots,x_{N_\alpha}^\alpha\}$, and an intra-layer adjacency matrix as $A^{[\alpha]} = (a_{ij}^\alpha) \in \mathrm{Re}^{N_\alpha \times N_\alpha}$, where

$$\alpha_{ij}^\alpha = \begin{cases} 1, & (x_i^\alpha, x_j^\alpha) \in E_\alpha, \\ 0. \end{cases} \quad (4)$$

for $1 \leq i \leq N_\alpha$, $1 \leq j \leq N_\beta$ and $1 \leq \alpha \leq M$. For an inter-layer adjacency matrix, we have $A^{[\alpha,\beta]}(a_{ij}^{\alpha\beta}) \in \mathrm{Re}^{N_\alpha \times N_\beta}$, where

$$\alpha_{ij}^{\alpha\beta} = \begin{cases} 1, & (x_i^\alpha, x_j^\beta) \in E_{\alpha\beta}, \\ 0. \end{cases} \quad (5)$$

A multiplex network is a partial case of inter-layer networks, and it contains a fixed number of nodes connected by different types of links. Multiplex networks are characterized by correlations of different nature, which enable the introduction of additional multiplexes.

For a multiplex network, the node degree k is already a vector

$$k_i = (k_i^{[1]},\ldots,k_i^{[M]}), \quad (6)$$

with the degree $k_i^{[\alpha]}$ of the node i in the layer α, namely

$$k_i^{[\alpha]} = \sum_j a_{ij}^{[\alpha]}, \quad (7)$$

while $a_{ij}^{[\alpha]}$ is the element of the adjacency matrix of the layer α. Specificity of the node degree in vector form allows describing additional quantities. One of them is the *overlapping degree* of node i:

$$o_i = \sum_{\alpha=1}^{M} k_i^{[\alpha]}. \quad (8)$$

The next measure quantitatively describes the inter-layer information flow. For a given pair (α,β) within M layers and the degree distributions $P(k^{[\alpha]}), P(k^{[\beta]})$ of these layers, we can defined the so-called *interlayer mutual information*:

$$I_{\alpha,\beta} = \sum\sum P(k^{[\alpha]},k^{[\beta]}) \log \frac{P(k^{[\alpha]},k^{[\beta]})}{P(k^{[\alpha]}),P(k^{[\beta]})}, \quad (9)$$

where $P(k^{[\alpha]},k^{[\beta]})$ is the joint probability of finding a node degree $k^{[\alpha]}$ in a layer α and a degree $k^{[\beta]}$ in a layer β. The higher the value of $I_{\alpha,\beta}$, the more correlated (or anti-correlated) is the degree distribution of the two layers and, consequently, the structure of a time series associated with them. We also find the mean value of $I_{\alpha,\beta}$ for all possible pairs of layers – the scalar $\langle I_{\alpha,\beta}\rangle$ that quantifies the information flow in the system.

The *multiplex degree entropy* is another multiplex measure which quantitatively describes the distribution of a node degree i between different layers. It

can be defined as

$$S_i = -\sum_{\alpha=1}^{M} \frac{k_i^{[\alpha]}}{o_i} \ln \frac{k_i^{[\alpha]}}{o_i}. \quad (10)$$

Entropy is close to zero if ith node degree is within one special layer of a multiplex network, and it has the maximum value when ith node degree is uniformly distributed between different layers.

4 HIGH-ORDER EXTENSION OF TEMPORAL NETWORKS

4.1 Time-Respecting Paths

Financial networks are strongly influenced by the ordering and timing of links. In their context of their temporality, we must consider *time-respecting paths*, an extension of the concept of paths in static network topologies which additionally respects the timing and ordering of time-stamped links (Holme and Saramäki, 2012; Kempe et al., 2002; Pan and Saramäki, 2011). For a source node v and a target node w, a time-respecting path can be presented by any sequence of time-stamped links

$$(v_0, v_1; t_1), (v_1, v_2; t_2), ..., (v_{l-1}, v_l; t_l), \quad (11)$$

where $v_0 = v, v_l = w$ and $t_1 < t_2 < ... < t_l$. Time ordering of temporal financial networks is important since it implies causality, i.e. a node i is able to influence node j relying on two time-stamped links (i,k) and (k,j) only if edge (i,k) has occurred before edge (k,j).

Apart the restriction on networks to have the correct ordering, it is common to impose a maximum time difference between consecutive edges (Scholtes et al., 2016), i.e. there is a maximum time difference δ and, example, two time-stamped edges $(i,k;t)$ and $(k,j;t')$ that contribute to a time-respecting path if $0 \leq t' - t \leq \delta$. If $\delta = 1$, we are usually interested in paths with short time scales. For $\delta = \infty$, we impose no restrictions on time-range and consider a path definition where links can be weeks or years apart.

4.2 High-Order Networks

The key idea behind this abstraction is that the commonly used time-aggregated network is the simplest possible time-aggregated representation, whose weighted links capture the frequencies of time-stamped links. Considering that each time-stamped link is a time-respecting path of length one, it is easy to generalize this abstraction to higher-order time-aggregate networks in which weighted links capture the frequencies of longer time-respecting paths.

There are several variants for encoding high-order interactions (Majhi et al., 2022). The first concept of high-order links represent *hyperlink*, which can contain any number of nodes. *Hypergraph* is the generalized notion of network which is composed of nodeset V and hyper-edges E that specify which nodes from V participate in which way.

Simplex is another mathematical abstraction to accomplish high-order interaction. Formally, a *k-simplex* σ is a set of $k+1$ fully interacting nodes $\sigma = [v_0, v_1, ..., v_k]$. Essentially, a node is 0-simplex, a link is 1-simplex, a triangle is 2-simplex, a tetrahedron is 3-simplex, etc. Since a standard graph is a collection of edges, *simplicial complexes* are collections of simplices $K = \{\sigma_0, \sigma_1, ..., \sigma_n\}$.

Figure 3 demonstrates examples of simplices and hyperlinks of orders 1, 2, and 3.

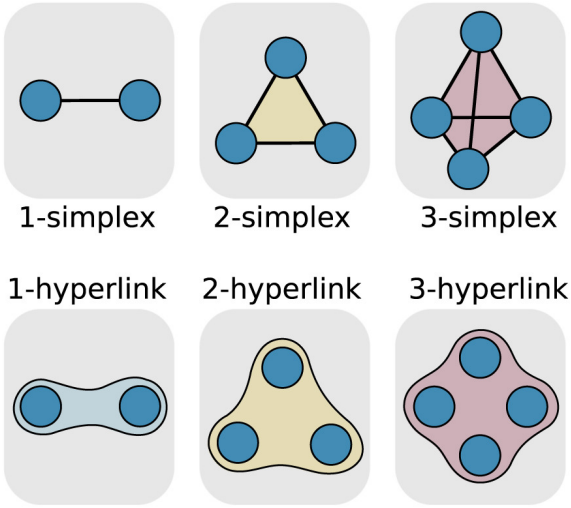

Figure 3: High-order connections in terms of simplices and hyperlinks. Adapted from (Battiston et al., 2020).

For a temporal network $G^T = (V^T, E^T)$ we thus formally define a kth order time-aggregated (or simply aggregate) network as a tuple $G^{(k)} = (V^{(k)}, E^{(k)})$ where $V^{(k)} \subseteq V^k$ is a set of node k-tuples and $E^{(k)} \subseteq V^{(k)} \times V^{(k)}$ is a set of links. For simplicity, we call each of the k-tuples $v = v_1 - v_2 - ... - v_k$ ($v \in V^{(k)}, v_i \in V$) a kth order node, while each link $e \in E^{(k)}$ is called a kth order link. Between two kth order nodes v and w exists kth order edge (v,w) if they overlap in exactly $k-1$ elements. Resembling so-called De Bruijn graphs (De Bruijn, 1946), the basic idea behind this construction is that each kth order link represents a possible time-respecting path of length k in the underlying temporal network, which connects node v_1

to node w_k via k time-stamped links

$$(v_1, v_2 = w_1; t_1), ..., (v_k = w_{k-1}, w_k; t_k). \quad (12)$$

Importantly, and different from a first-order representation, kth order aggregate networks allow to capture *non-Markovian* characteristics of temporal networks. In particular, they allow to represent temporal networks in which the kth time-stamped link $(v_k = w_{k-1}, w_k)$ on a time-respecting path depends on the $k-1$ previous time-stamped links on this path. With this, we obtain a simple static network topology that contains information both on the presence of time-stamped links in the underlying temporal network, as well as on the ordering in which sequences of k of these time-stamped links occur.

4.3 Degree Centrality

Network centralities are node-related measures that quantify how "central" a node is in a network. There are many ways in which a node can be considered so: for example, it can be central if it is connected to many other nodes (degree centrality), or relatively to its connectivity to the rest of the network (path based centralities, eigenvector centrality). One of the simplest centrality measure is the *degree of a node*, which counts the number of edges incident to an ith node.

For any adjacency matrix the degree of a node i can be defined as

$$D_i = \sum_j A_{ij}. \quad (13)$$

High-order degree centrality counts the number of kth-order edges incident to the kth-order node i. To get a scalar value which will serve as an indicator of high-order dynamics, we obtain mean degree D_{mean}:

$$D_{mean} = \frac{1}{N} \sum_{i=1}^{N} D_i. \quad (14)$$

Except this measure, we can calculate nth moment of the degree distribution, which can be defined as

$$\langle k^n \rangle = \sum_{k_{\min}}^{\infty} k^n p_k \approx \int_{k_{\min}}^{\infty} k^n p_k dk. \quad (15)$$

In this study we will present the dynamics of the first moment, which is the mean weighted degree of a network, and its high-order behavior.

4.4 Assortativity Coefficient

Assortativity is a property of network nodes that characterizes the degree of connectivity between them. Many networks demonstrate "assortative mixing" on their nodes, when high-degree nodes tend to be connected to other high-degree nodes. Other networks demonstrate disassortative mixing when their high-degree nodes tend to be connected to low-degree nodes. Assortativity of a network can be defined via the Pearson correlation coefficient of the degrees at either ends of an edge. For an observed network, we can write it as

$$r = \left(M^{-1} \sum_i j_i k_i - \left[M^{-1} \sum_i \frac{1}{2} (j_i + k_i) \right]^2 \right) \Bigg/ \left(M^{-1} \sum_i \frac{1}{2} \left(j_i^2 + k_i^2 \right) - \left[M^{-1} \sum_i \frac{1}{2} (j_i + k_i) \right]^2 \right), \quad (16)$$

where $-1 \leq r \leq 1$; j_i, k_i are the degrees of the nodes at the ends of the ith edge, with $i = 1, ..., M$, where M is the number of edges of a network.

This correlation function is zero for no assortative mixing. If $r = 1$, then we have perfect assortative mixing pattern. For $r = -1$, we can observe perfect disassortativity.

Studying financial networks, with time-respecting paths, we can consider four type of assortativity: $r(in,in), r(in,out), r(out,in), r(out,out)$, which will correspond to tendencies to have similar in and out degrees. We can denote one of the studied in/out pairs as (α, β). Suppose, for a given ith edge, we have got the source (i.e. tail) node of the edge and target (i.e. head) node of the edge. We can denote them as α-degree of the source (j_i^{α}) and β-degree of the target (k_i^{β}). Assortativity coefficient for degrees of a specific type can be defined as

$$r(\alpha, \beta) = \frac{\sum_i \left(j_i^{\alpha} - \overline{j^{\alpha}} \right) \left(k_i^{\beta} - \overline{k^{\beta}} \right)}{\sqrt{\sum_i \left(j_i^{\alpha} - \overline{j^{\alpha}} \right)^2} \sqrt{\sum_i \left(k_i^{\beta} - \overline{k^{\beta}} \right)^2}}, \quad (17)$$

where $\overline{j^{\alpha}}$ and $\overline{k^{\beta}}$ are the average α-degree of sources and β-degree of targets.

5 EMPIRICAL RESULTS

To build indicators (indicators-precursors) based on multiplex and high-order networks, the following is done:

- databases of 6 most influential stock market indices for the period from 02.01.2004 to 18.10.2022 were selected for multiplex analysis

(see figure 4). The data were extracted using Yahoo! Finance API based on Python programming language (Aroussi, 2022);

- the indicators described in the previous sections were calculated using the sliding window procedure (Bielinskyi et al., 2022; Soloviev et al., 2020; Bielinskyi et al., 2021c,b; Kiv et al., 2021; Bielinskyi and Soloviev, 2018; Bielinskyi et al., 2020). The essence of this procedure is that: (1) a fragment (window) of a series of a certain length w was selected; (2) a network measure was calculated for it; (3) the measure values were stored in a pre-declared array; (4) the window was shifted by a predefined time step h, and the procedure was repeated until the series was completely exhausted; (5) further, the calculated values of the network measure were compared with the dynamics of the stock index. Subsequently, conclusions were drawn regarding the further dynamics of the market. In our case, window length $w = 500$ days and time step $h = 10$ day. The choice of step was limited by the counting time for high-order networks;
- multiplex and high-order indicators are compared with the Dow Jones Industrial Average (DJIA) index.

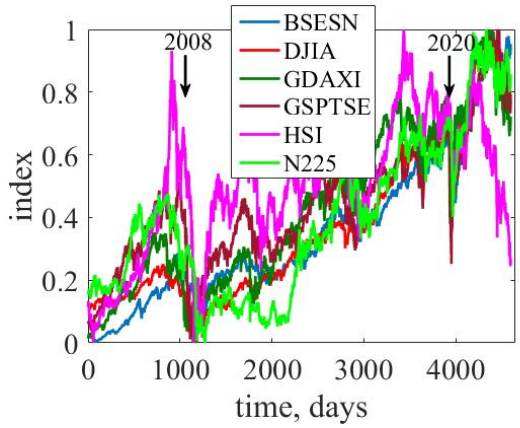

Figure 4: The dynamics of stock market indices for studying multiplex characteristics.

In figure 5 presented the dynamics of inter-layer mutual information (I) and multiplex degree entropy (S) along with the DJIA index.

From figure 5 we can see that multiplex mutual information increases before the crisis of 2008. Also, it noticeably becomes higher before COVID-19 crash. For the last months, it demonstrates decreasing pattern, which indicates that the economies of different countries may be experiencing different evolutions now. Nevertheless, it can be seen that, as a rule, this

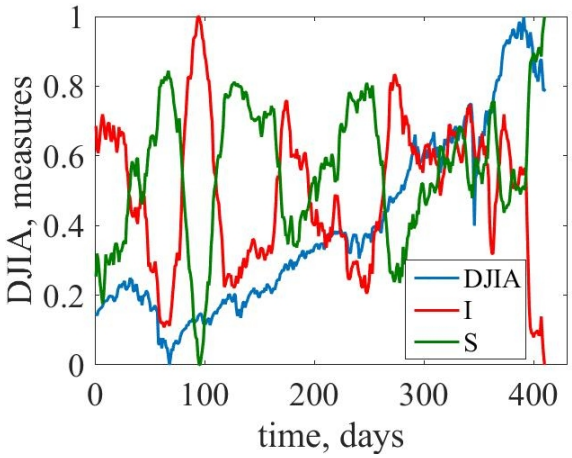

Figure 5: The dynamics of inter-layer mutual information (I) and multiplex degree entropy (S) along with the DJIA index.

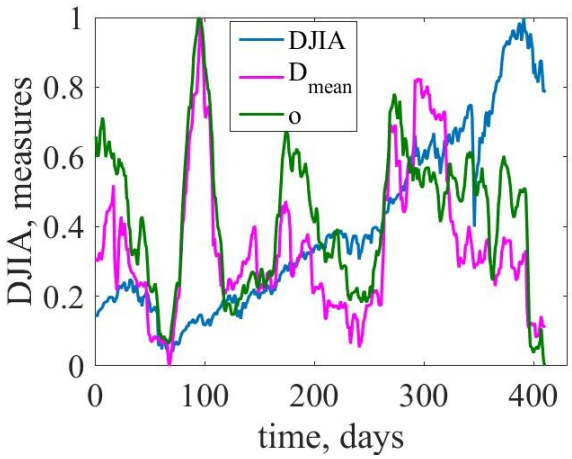

Figure 6: The dynamics of the mean degree (D_{mean}) and overlapping degree (o) along with the DJIA index.

indicator is characterized by growth, indicating an increase in the interconnection of the economies of different countries. In a crisis, this indicator usually declines, demonstrating different resistance to the collapse events of the stock markets of countries and the difference in the actions that they take. Entropy indicator shows asymmetric behavior

Next, we compare one of the multiplex measure, overlapping degree (o), with the mean degree of a network (D_{mean}). Figure 6 represents this result.

In figure 6 we can see that both D_{mean} and o are characterized by similar dynamics. These indicators increase near the crash, which indicates an increase in the concentration of connections for some network nodes, and further, based on the indicators during the crisis, there is a decline in concentration both in the dynamics of the DJIA and the inter-layer connectedness of stock indices. We may see that the multiplex

approach does not significantly change the dynamics of the concentration degree indicator in comparison with the indicator based on the classical univariate graph.

Figure 7 demonstrates the dynamics of mean weighted degree (equation (15)) for order 1 and 2 along with the DJIA index.

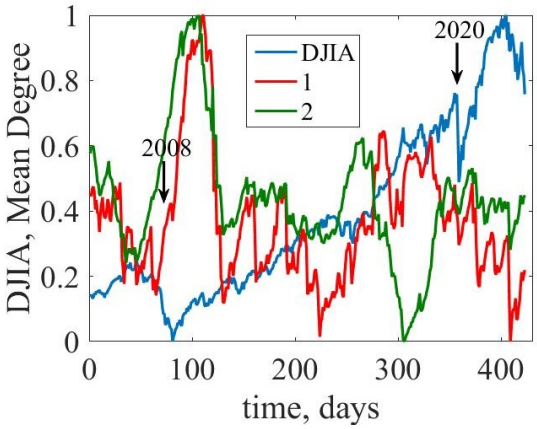

Figure 7: The dynamics of first- and second-order mean (weighted) degree along with the DJIA index.

In figure 7 we can see that the second-order D_{mean} is slightly different from the first-order one. The second-order D_{mean} starts to increase a slightly earlier before the crisis of 2008. We can see that before crisis of 2020 second-order D_{mean} declines more noticeably comparing to the first-order one. However, this difference between the first and second order is still insignificant, what can we say about the fact that the classical visibility graph can reflect all the information that the series under study can represent.

Next, let us present high-order dynamics of the assortativity coefficient for the DJIA index (see figure 8).

Figure 8 presents the assortativity coefficient for first, second, and third orders. Assortativity declines before crashes and increases during them. We see that high-orderness does not change radically change the dynamics of this indicator. Third-order assortativity responds better for the crash of 2008, but worse for the COVID-19 crisis, comparing to first- and second-order assortativity.

6 CONCLUSIONS

In this article, we have presented methods to measure and model systems with casual, multiplex, and high-order interactions. From our analysis, we have found that typically non-Markovian, non-stationary,

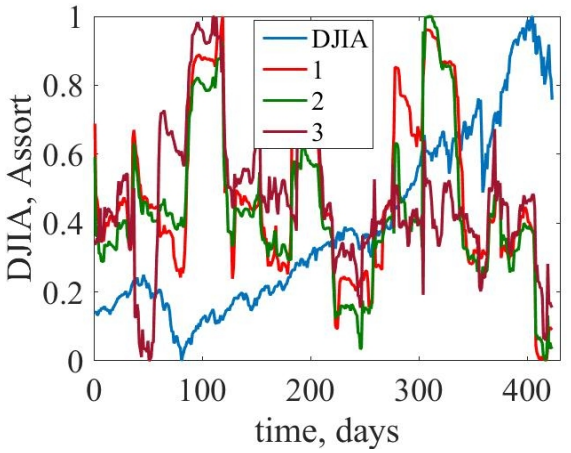

Figure 8: The dynamics of first-, second-, and third-order assortativity along with the DJIA index.

non-linear systems are characterized by long-range spatio-temporal correlations which are better described by the high-order paradigm. Typically, high-order connectivity is described in terms of hypergraphs (Schölkopf et al., 2007; de Arruda et al., 2020; Carletti et al., 2020) or simplicial complexes (Schaub et al., 2020; Torres and Bianconi, 2020; Skardal and Arenas, 2020). Such richer types of links bring new possibilities to go beyond typical nodes and encode into one node edges, triangles, tetrahedra, etc. to investigate higher-order clusters and temporal dependencies.

We have presented indicators (indicators-precursors) based on classic visibility graphs, multiplex networks, and high-order networks. In this study we have used such network measures as the mean degree of a node D_{mean}, first-moment degree (mean weighted degree) of a network, assortativity coefficient, inter-layer mutual information I, multiplex degree entropy S, and mean overlapping degree of a network o. We have constructed the visibility graph relying on the time series of the Dow Jones Industrial Average (DJIA) index. We have studied multiplex network dynamics using a database that consists of 6 of the most developed and capitalized stock indices of different countries and which include companies from different sectors. We have chosen the period from 02.01.2004 to 18.10.2022. Each indicator was calculated using the sliding window algorithm. We have shown that multiplex and high-order networks do not substantially differ dynamically from the traditional pairwise visibility model. This may indicate that the classical visibility graph reflects all possible short-term and long-term dependencies in the values of the DJIA index. All the presented measures work similarly, like indicators (indicators-precursors) of critical

financial events, increasing or decreasing before and during them. Although multiplex and high-order network indicators give promising results, it still needs further development and improvements for studying complex financial time series. The solution may lie in the framework that combines Markov chains of multiple, higher orders into a multi-layer graphical model that captures temporal correlations in pathways at multiple length scales simultaneously (Scholtes, 2017). Another perspective lies in the use of neuro-fuzzy forecasting and clustering methods of complex financial systems (Bielinskyi et al., 2021a; Bondarenko, 2021; Kmytiuk and Majore, 2021; Kobets and Novak, 2021; Kucherova et al., 2021; Lukianenko and Strelchenko, 2021; Miroshnychenko et al., 2021).

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Application of Multidimensional Statistical Analysis Technology for Grouping Regions by the Investment Attractiveness Level

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Abstract: The paper is devoted to studying multidimensional statistical analysis tools for grouping regions by the level of their investment attractiveness and identifying changes in the structure of regions in the context of the continued destructive impact of the COVID-19 pandemic. An analysis of approaches to assessing investment attractiveness identified their strengths. Insufficient attention to the application of methods of multidimensional statistical analysis to a grouping of regions is stated. The authors consider the clustering of regions of Ukraine in the context of their level of investment attractiveness by the method of *k*-means and identify their structure according to the level of investment attractiveness in 2019 and 2020 in the context of the COVID-19 pandemic. To verify the correctness of the conclusions, the method of principal components with the rotation of the space of the selected factors by the quartimax technique. Further grouping of regions in the space of selected principal components showed results identical to the application of the cluster analysis method. Potential investors can use the research results to determine priority areas of investment. Also, the results are useful for local self-government bodies, as they provide information on the relative level of investment attractiveness of a specific region compared to other territorial units and also allow identifying weak points in specific areas of activity.

1 INTRODUCTION

Sustainable socio-economic development of territories is associated with the need to intensify investment activities. It is primarily aimed at forming the financial basis for improving the efficiency and effectiveness of enterprises, creating new jobs, and achieving high social standards of living. Achieving this goal requires using analytical tools as part of appropriate mechanisms for managing regional development. An essential component of such tools is economical and mathematical modeling. Using relevant data and fitting models provides quantitative and qualitative assessments of the state and socio-economic development trajectories. One of the ways to create an analytical basis for determining the strategy of regional policy in the context of financial support for socio-economic development is to assess the investment attractiveness of regions.

Significant structural and technological economic changes caused by globalization, increasing competition in foreign and domestic markets, and the consequences of the COVID-19 pandemic require increased investment, which is limited financial resources and a critical task. Therefore, ensuring the region's investment attractiveness is a strategic task for developing business structures, which will help attract investment, primarily from foreign investors.

Therefore, in the current conditions of production and economic activities, issues related to assessing the investment attractiveness of regions and their grouping to determine areas for intensification of investment processes, search and use of reserves to improve the efficiency of regional investment are of priority importance.

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2 LITERATURE REVIEW

ssessing the region's investment attractiveness is essential in developing a strategy for innovation at regional and national levels. Note that the investment volume isn't always directly determined by the high level of investment attractiveness. This is due to many other factors that determine investor decision-making. In particular, such factors are various indices and ratings regularly published by international institutions and characterize the business environment, business conditions, actual investment activities, and the attractiveness of countries for investment. In particular, it can be used such evaluations like the World Bank Ranking "Doing Business" (World Bank, 2021); Index of Economic Freedom, provided by the Heritage Foundation (Heritage Foundation, 2020); Corruption Perceptions Index (CPI), compiled by the international anti-corruption organization "Transparency International" (Transparency International, 2020); Foreign Direct Investment Confidence Index (Kearney, 2020); Global Innovation Index (WIPO, 2020); European Business Association Investment Attractiveness Index (EBA, 2020); Credit rating developed by Moody's Investors Service (Moody's, 2020); World Countries' Ranking on the Global Competitiveness Index, provided by the World Economic Forum (WEF, 2020); World Competitiveness Ranking, provided by the International Institute for Management Development (IMDWCC, 2020); The KOF Globalization Index, published by the KOF Swiss Economic Institute, reflects the scale of the country's integration into the world (KOF, 2020) and many others.

These ratings provide the necessary information for potential investors on the characteristics of the country's business environment and possible investment risks. Naturally, countries with high ratings are more attractive regarding return on investment. On the other hand, countries with low ratings may also be attractive to investors, particularly for short-term investments, resulting from competition for coverage of developing countries.

These ratings should be noted that characterize the country's business environment. At the same time, investors are usually interested in specific areas, territorial units, markets, sectors of the economy, and business entities. Such assessments of the investment attractiveness of certain regions of Ukraine are provided by the State Statistics Service of Ukraine (SSCU, 2003) and the Ministry of Development of Communities and Territories of Ukraine (MCTDU, 2021).

The issue of investment attractiveness is also the focus of research. The formation of the theoretical basis for the study of the category of investment attractiveness in the context of its relationship with the investment climate, and investment risks, taking into account current trends in economic development, is reflected in the works (Kaminskyi et al., 2019; Stadnyk et al., 2020; Korenyuk and Kopil, 2018; Kyshakevych et al., 2020; Godlewska-Majkowska, 2018; Jac and Vondrackova, 2018). Researchers presented a modern understanding of the category of investment attractiveness, its content and essential characteristics, and the impact on the socio-economic development of individual regions and the country as a whole.

An important issue in modeling investment attractiveness is forming an information base for calculating various estimates of the studied characteristics. The solution to such problems is considered in (Kyshakevych et al., 2020; Jac and Vondrackova, 2018; Bushynskyi, 2020; Leshchuk, 2020; Lagler, 2020; Swidynska and De Jesus, 2020). It should be noted that the results of scholars' investigations in this field are differed both in the number of indicators and their focus in the context of reflecting certain aspects of investment activities. At the same time, the authors' positions coincide with the views that the indicators should reflect the economic, financial, and social aspects of regional development.

Modeling the investment attractiveness of regions is mainly based on statistical methods. Their application is based on quantitatively measurable indicators that reflect social, economic, environmental, and investment development components. This approach uses regression models, that presented in papers (Windhyastiti et al., 2020; Blahun et al., 2017; Vartsaba and Leshuk, 2017; Kikkas and Krasnozhenova, 2018); correlation analysis techniques (Blaschke, 2022; Dorozynski and Kuna-Marszałek, 2016); models based on neural networks (Bruneckiene et al., 2019). At the same time, the issue of identifying the level of investment attractiveness and comparing regions on this indicator is out of the attention of researchers. The approach based on comprehensive index assessment technology is quite common. It is successfully used in solving the problems of ranking regions by socio-economic development (Hryhoruk et al., 2019b,a; Mazziotta and Pareto, 2014; Meyer et al., 2016). The application of this approach to assessing investment attractiveness is reflected in studies (Swidynska and De Jesus, 2020; Kyshakevcyh and Nakhaeva, 2021; Yelnikova, 2020; Sizova et al., 2017).

Among the shortcomings of the comprehensive index assessment technology application presented in these investigations, it should be noted that they use a fairly large set of initial indicators. This makes it

difficult to identify the significance of their impact on the final result and eliminates the differentiating ability of the designed composite index. These shortcomings negatively affect the ability to group the set of studied objects due to the high density of values on the composite index scale. Also out of consideration is the definition of the level of investment attractiveness of regions, which complicates the assessment of differences between regions on the calculated index.

The problems of rating regions can also be solved with the application of multidimensional statistical analysis technology, that described, in particular, in papers (Tenreiro Machado and Mata, 2015a,b; Meyer and De Jongh, 2018; De Jongh and Meyer, 2019; Walesiak, 2017; Gorbatiuk et al., 2019; Hryhoruk et al., 2020b,a; Andrusiak et al., 2022). Adaptation of multidimensional analysis methods to assess investment attractiveness is considered in studies (Cheba, 2017; Danylchuk et al., 2019; Shinkarenko et al., 2019; Musolino and Volget, 2020; Roszko-Wójtowicz and Grzelak, 2021).

At the same time, applying these methods is focused mainly on solving the problem of grouping regions in terms of investment attractiveness. The analysis of structural shifts within the constructed homogeneous groups remains out of the attention of scientists, as well as the comparison of grouping results obtained by different techniques.

According to the results of the analysis of publications, it can be concluded that there is significant diversity in approaches to assessing the investment attractiveness of regions. Among the disadvantages, we can note that the calculations are carried out without considering the dynamic and qualitative changes in the environment.

Also, the use of a large number of baseline partial indicators, to some extent, blurs the study's results and gives only a general description of the socio-economic condition of the region and the characteristics of investment activities.

The significant variety of calculated estimates and the lack of clear conclusions and recommendations for their practical application necessitates the further study of the problem of assessing the investment attractiveness of regions in the context of their grouping by using different techniques to solve this problem with the further comparison of grouping results and structural changes within groups.

The solution to these problems has led to the direction of research in this study.

3 PROBLEM DESCRIPTION AND METHODOLOGY

A large number of different indicators characterize modern investment processes. This multidimensionality of the description makes it difficult to solve problems of assessing the various characteristics of these processes, particularly the grouping of regions by the level of investment attractiveness. As noted earlier, one way to solve classification problems is using cluster analysis techniques. Unlike combinational grouping, this approach allows you to create groups of similar objects of observation, considering all the features at once. The degree of similarity, in this case, is usually the Euclidean distance between objects in the multidimensional space of primary indicators. One of the cluster analysis methods is the k-means method, which belongs to the group of iterative clustering ones.

Consider a brief description of the mathematical model of the k-means method (Hryhoruk et al., 2021). Suppose there are m observations, each characterized by n indicators $X_1, X_2, \ldots, X_n$.

We need to divide these observations into k clusters that do not intersect. At the initial stage, we choose k points-objects that will act as centers of clusters. Denote them by $C_1^{(0)}, C_2^{(0)}, \ldots, C_k{}^{(0)}$. The weight of each cluster will initially be equal to one: $w_1^{(0)} = 1, w_2^{(0)} = 1, \ldots, w_k{}^{(0)} = 1$. The index of the corresponding center will be considered the index of the corresponding cluster. Although the selected centers may move to other clusters during the subsequent iterative procedure, the indexing of the clusters will not change.

In the first step, each of the $(n-k)$ objects that are not the clusters' centers is included in one of the formed clusters. The criterion for such movement is the minimum distance to the cluster's center. The center of the cluster and its weight are recalculated. For example, for a point M_{k+1} with coordinates ($X_{k+1,1}$; $X_{k+1,2}$;...; $X_{k+1,n}$) the recalculation is performed according to the formulas:

$$C_j^{(0)} = \frac{w_j^{(0)} c_j^{(0)} + M_{k+1}}{w_j^{(0)} + 1}, \tag{1}$$

$$w_j^{(0)} = w_j^{(0)} + 1. \tag{2}$$

In the case of equality of two or more distances to the centers of clusters, the point-object joins the cluster with a smaller sequence number. Note that in practice, such a situation is unlikely.

The resulting centers and corresponding cluster weights are taken as the initial values of the related characteristics for the next iteration.

All stages of the further iterative process use formulas (1) and (2) and the whole set of initial data $M_1, M_2, ..., M_m$. At the same time, the weight of clusters continues to increase.

The objects can also be grouped by expanding them in some new space of latent scales, which reflect the generalizing characteristics. In particular, the principal components method can be constructed in such a space.

In matrix form, the model of the method is described by the formula:

$$Z^T = W \cdot F^T, \tag{3}$$

where Z is an initial standardized indicators matrix;

W – factor loadings matrix; it reflects relations between initial indicators and principal components;

F – principal components matrix.

Factor loadings matrix is calculated using eigenvalues and appropriate eigenvectors of R – initial indicators correlation matrix:

$$W = V \cdot \Lambda^{(-1)}, \tag{4}$$

where W – factor loadings matrix;

V – normalized eigenvectors matrix;

Λ – eigenvalues matrix.

The rule obtains the initial indicators correlation matrix:

$$R = \frac{Z^T \cdot Z}{m-1}, \tag{5}$$

where R – correlation matrix;

Z – initial standardized indicators matrix.

The standardization procedure for initial indicators uses a formula:

$$Z_{ij} = \frac{X_{ij} - \bar{X}_j}{s_j}, \tag{6}$$

where Z_{ij} – initial standardized indicators values;

X_{ij} – initial indicators values;

$\bar{X}_j$ – average sample value of the indicator X_j;

s_j – sample standard deviation of the indicator X_j;

$i = 1..m; j = 1..n$.

The formula obtains the principal components matrix:

$$F = Z \cdot W \cdot \Lambda^{-1}. \tag{7}$$

This matrix contains the coordinates of objects under study in a principal components space.

Not all the principal components are selected for practical application, but only the most essential part in explaining the variance of the initial indicators (information contained in the initial indicators). Given that the eigenvalues of the correlation matrix are considered to be ordered in descending their values in the calculation procedure, the weight of each subsequent principal component is reduced. Usually, the first two principal components are sufficient to achieve an "acceptable" level of explanation of the information contained in the set of initial indicators, at least 70 %.

Meaningful interpretation of the selected principal components (search for names for them) is carried out by considering the absolute values of the respective factor loads. The initial indicators that will be used to interpret the appropriate principal component include those for which the factor loadings absolute value between them and the corresponding principal component is not less than 0.75. The factor load reflects the correlation between the principal component and the related indicator. To improve the procedure of interpretation of the principal components by the problem's content, the constructed factor space is rotated with a corresponding change in both factor loadings and values of the principal components. The result is a "simple structure" space where the principal components are closely related to some initial indicators and weak to others.

4 RESULTS AND DISCUSSIONS

Consider the application of cluster analysis of the grouping of Ukraine's regions by indicators that reflect their investment attractiveness. The choice of the initial indicators set will be made based on the following considerations:

- indicators should reflect both the characteristics of investment activities of the region's business entities and the socio-economic development of the region;
- indicators should be comparable by the values for different regions;
- the indicators must be standardized, i.e., have a sample mean equal to zero and a sample standard deviation equal to one. This procedure is needed because clustering is based on a matrix of differences between the studied points-regions in the multidimensional space of the initial indicators, which is essentially a matrix of Euclidean distances between them. Therefore, for the objectivity of the calculations, it is necessary to remove the measurement units' influence on estimates of distances between objects.

Based on the recommendations of scholars presented in studies (Korenyuk and Kopil, 2018; Kyshakevych et al., 2020; Godlewska-Majkowska, 2018; Jac and Vondrackova, 2018; Bushynskyi, 2020; Leshchuk, 2020; Lagler, 2020; Vartsaba and Leshuk, 2017; Dorozynski and Kuna-Marszałek, 2016) and taking into account the above considerations, we have

formed the following set of initial indicators for calculations:

X_1 – Volume of capital investments per capita, UAH;

X_2 – Volume of foreign direct investment per capita, USD;

X_3 – Gross regional product (at actual prices) per capita, UAH;

X_4 – Disposable income per capita, UAH;

X_5 – Volume of exports of goods per capita, USD;

X_6 – Volume of sold industrial products per capita, UAH;

X_7 – Total of construction work per capita, UAH;

X_8 – Employment rate of the population aged 15-70, in percent;

X_9 – Unemployment rate of the population aged 15-70 years (according to the methodology of the ILO), in percent.

We use data for 2019 and 2020 from the materials of the State Statistics Service of Ukraine (SSSU, 2022) and the Ministry of Development of Communities and Territories of Ukraine (MCTDU, 2021) for calculations. Obtained results will also be compared to assess changes in regions' position in the groups in which the regions are located. To present the region's names conveniently and briefly, we point out the correspondence between each region's name and the appropriate code (table 1). Initial data for calculations are written in table 2 and table 3.

Table 1: The relationships between the quantitative values of the desirability scale and qualitative development levels of group.

Code	Region	Code	Region
C_1	Vinnytsia	C_13	Mykolaiv
C_2	Volyn	C_14	Odesa
C_3	Dnipro	C_15	Poltava
C_4	Donetsk	C_16	Rivne
C_5	Zhytomyr	C_17	Sumy
C_6	Zakarpattia	C_18	Ternopil
C_7	Zaporizhzhia	C_19	Kharkiv
C_8	Ivano-Frankivsk	C_20	Kherson
C_9	Kyiv	C_21	Khmelnytskyi
C_10	Kyrovohrad	C_22	Cherkasy
C_11	Luhansk	C_23	Chernivtsi
C_12	Lviv	C_24	Chernihiv

Let us cluster Ukraine's regions according to the selected set of indicators using the k-means method. Define the number of clusters for grouping regions as equal to three: a cluster of regions with a high level of investment attractiveness, a cluster of regions with a medium level of investment attractiveness, and a cluster of regions with a low level of investment attractiveness. We make calculations using "Statistica" software. The results of clustering are shown in figure 1 and figure 2. The numbering of clusters, in this case, is determined by the used software arbitrarily. Let us provide a meaningful description of each cluster according to 2019 data.

Cluster number 1 contains 6 regions: Volyn, Donetsk, Zakarpattia, Kyrovohrad, Luhansk and Ternopil. In our opinion, this cluster can be called a group of regions with a low level of investment attractiveness. Note that the regions of this cluster are not industrially developed, which negatively affects their attractiveness for investment. In addition, the effects of the COVID-19 pandemic have had a significant negative impact on the development of these regions. Cluster number 2 contains regions with an average level of investment attractiveness. It is the most complete and consists of 14 points, which is quite natural in compliance with the essence of the division of the typical characteristics. The cluster with a high level of investment attractiveness includes cluster number 3, which includes Dnipro, Kyiv, Zaporizhzhia, and Poltava regions. For these regions, there are high values of the indicators presented in table 2, particularly the volume of foreign direct investment and relatively high employment rate, which allowed to give the cluster just such an interpretation. In addition, these regions have developed industries, which is also reflected in the indicator's values.

Comparing the cluster's structure obtained from 2020 data (figure 2), we can conclude that the fullness of clusters has not changed compared to the previous year. This indicates that there have been no significant changes in the investment attractiveness of Ukraine's regions in 2020. Although several normative acts have been adopted at the legislative level to facilitate attracting investments into Ukraine's economy, their positive impact has not yet manifested itself. On the other hand, it is possible to state a certain stabilization of indicators of socio-economic development of Ukraine's regions during the COVID-19 pandemic.

Let us consider the data of application of the principal components method for grouping Ukraine's regions by the level of investment attractiveness. We create the two-dimensional space of latent indicators obtained by applying this method and project points-regions on this space. To construct latent indicators, we use the quartimax method for rotations of factor space, which will contribute to an adequate representation of points in the new space and the identification of meaningful interpretation of new axes.

Calculations also are performed using Statistica software. The calculations' results of factor loadings are presented in table 4, and the values of points-

Table 2: Initial data for calculation for 2019 (MCTDU, 2021; SSSU, 2022).

Code	Values								
	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9
C_1	9196.8	153.2	71104	64729	937.3	52478.4	6650.5	58.0	9.4
C_2	11800.5	297.5	58297	52879	671.6	30585.3	2259.4	50.9	10.6
C_3	19841.6	1191.1	114784	87130	2477.8	142289.0	6291.1	59.5	7.7
C_4	6789.2	338.4	45959	39141	1116.8	68439.6	1691.2	50.9	13.6
C_5	6095.3	202.7	62911	61961	592.3	37457.1	2227.8	58.5	9.6
C_6	7010.9	288.1	41706	47495	1186.9	19086.0	1770.8	55.4	9.1
C_7	8246.3	538.3	85784	75407	1815.8	114981.1	2270.5	58.1	9.5
C_8	5969.9	529.3	57033	55537	665.1	48750.1	2701.6	56.6	7.2
C_9	27299.0	930.2	112521	75146	1098.1	68058.8	5833.2	59.3	5.9
C_10	7536.1	80.0	67763	58290	752.7	34338.9	2194.2	55.6	11.0
C_11	1303.0	209.0	16301	24477	71.3	10219.1	310.2	58.8	13.7
C_12	10137.4	446.8	70173	65691	874.9	41829.4	4391.2	57.8	6.5
C_13	10394.4	271.6	70336	63685	1912.6	55148.1	3864.1	59.1	9.3
C_14	8372.1	540.3	72738	72805	581.9	25815.1	7557.4	58.3	5.9
C_15	15316.4	841.3	123763	71627	1508.9	120922.5	5472.7	56.6	10.6
C_16	5225.1	116.7	49044	54183	381.1	37058.2	2872.8	58.4	8.3
C_17	6399.4	184.6	62955	65310	821.9	44941.0	1448.5	59.8	7.7
C_18	8016.4	47.7	46833	49843	416.7	19914.5	2325.0	53.8	10.0
C_19	7953.8	287.6	86904	65534	530.6	69605.2	5603.2	62.1	5.0
C_20	11420.8	237.9	52922	57110	259.6	29604.1	1777.3	58.9	9.6
C_21	6812.2	161.6	59583	58008	509.9	34392.0	3061.2	57.0	8.0
C_22	8143.2	298.7	76904	58808	720.1	61514.6	1732.7	59.3	8.3
C_23	3716.9	58.9	37441	48255	236.8	15093.2	2347.4	59.0	6.9
C_24	7965.9	447.4	69725	58904	808.6	34334.3	1907.2	58.9	10.2

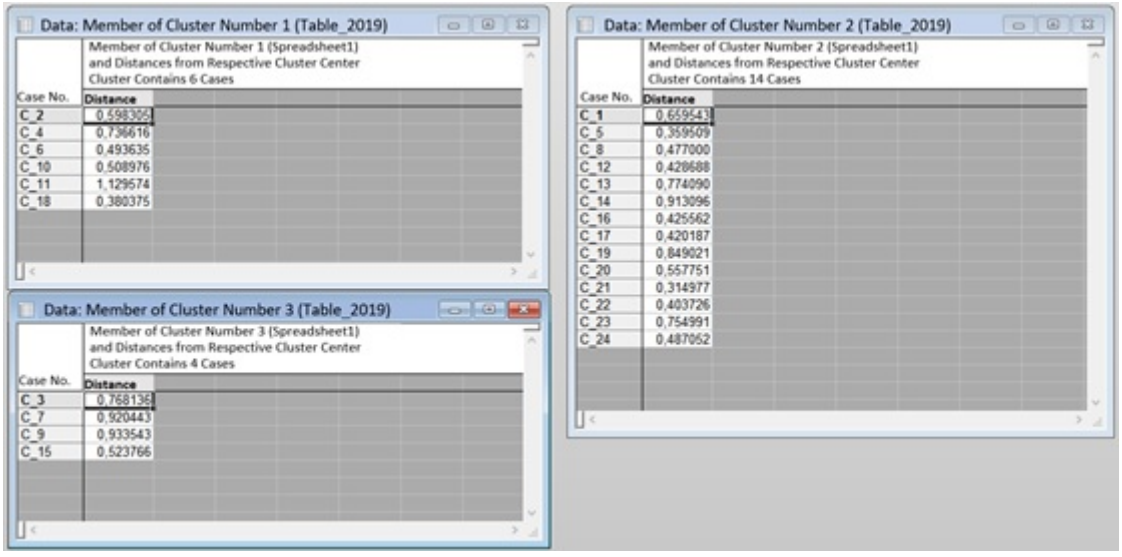

Figure 1: Clustering results of Ukraine‘s regions for data 2019.

objects in the new space – are in table 5. Note that in this case, the degree of explanation of the variance of the initial indicators by selected factors (degree of latent indicators informativeness) is 77 % for 2019 and 79 % for 2020 data. These indicators indicate the sufficiency of allocating exactly two principal components as latent indicators for further analysis.

Table 4 analysis allows us to provide such an interpretation of the selected principal components. Component F_1 has high factor loadings values for the initial indicators $X_1 - X_6$, and low for X_8 and X_9. Therefore, we can conclude that F_1 is an economic compo-

Table 3: Initial data for calculation for 2020 (MCTDU, 2021; SSSU, 2022).

Code	Values								
	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9
C_1	6226.8	249.9	83175	70691	896.3	50771.9	7042.7	56.2	10.7
C_2	9319.5	240.8	73215	56603	624.7	31231.1	2465.0	48.9	12.5
C_3	15208.9	1426.0	122379	92083	2403.0	135366.4	5723.9	58.0	8.6
C_4	5355.9	424.0	49422	41662	956.0	62158.9	2470.6	49.2	14.9
C_5	5615.5	266.6	70247	67187	567.0	39163.6	1783.2	55.3	10.9
C_6	3192.3	193.3	48861	51073	1078.1	19249.3	1546.7	53.7	10.6
C_7	5864.6	851.4	91498	81949	1743.8	111716.8	1871.0	56.0	10.7
C_8	3630.9	402.0	63254	60276	555.3	45016.0	2822.3	54.1	8.4
C_9	12929.1	735.8	123267	79263	1102.6	70505.2	7089.9	57.8	6.9
C_10	5562.3	188.4	77816	63472	985.0	37684.9	1486.2	53.1	12.7
C_11	1086.3	74.4	18798	26714	60.9	8904.5	339.1	56.4	15.4
C_12	5880.9	639.3	85198	71150	927.4	44425.4	5709.3	56.0	7.6
C_13	5422.3	318.8	82149	68289	2018.3	55878.6	3017.5	57.3	10.7
C_14	6757.9	470.7	82903	80164	573.4	29687.1	12078.5	56.8	7.1
C_15	11829.0	1411.6	134449	77547	1680.3	115483.4	5940.1	54.8	12.0
C_16	3165.9	229.4	58332	58814	408.0	38908.7	2862.1	56.1	9.3
C_17	4763.8	321.9	70576	71117	918.7	43165.9	1612.1	56.8	9.4
C_18	5510.9	47.5	54833	55570	433.2	20508.6	2511.5	51.6	11.5
C_19	6178.4	344.0	92864	73218	556.1	66393.8	5509.5	59.9	6.2
C_20	3536.8	155.6	59987	63073	275.3	32008.3	1279.4	56.8	11.3
C_21	5784.0	94.8	65916	64824	531.1	37850.9	5301.7	54.8	9.9
C_22	4627.2	176.7	86319	64254	684.1	64414.0	2171.5	57.0	9.5
C_23	2533.5	61.8	46136	53875	187.5	15525.8	2428.7	56.5	8.9
C_24	5599.5	455.0	78118	64933	905.4	35004.1	2501.6	56.4	11.9

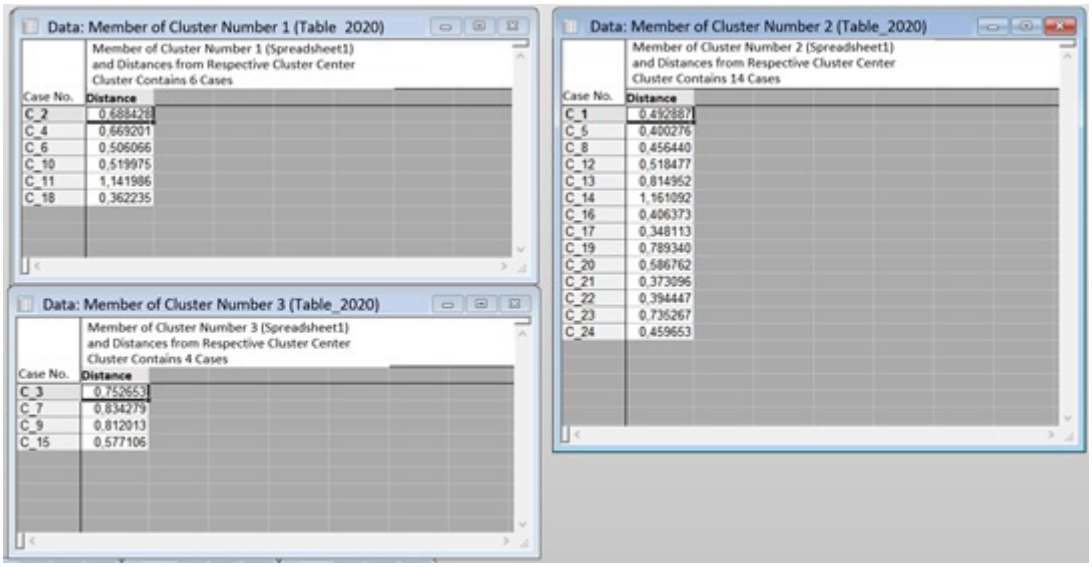

Figure 2: Clustering results of Ukraine's regions for data 2020.

nent of investment attractiveness, as the corresponding indicators $X_1 - X_6$ are characteristics of economic activity. For indicators X_8 and X_9 there are high values of factor loadings for component F_2 and low for F_1. Based on the essence of indicators X_8 and X_9, we can conclude that F_2 can be interpreted as a social component of investment attractiveness. For indicator X_7, the value of factor loadings for the principal component F_1 in 2019 exceeds the corresponding value for component F_2, although this excess is insignifi-

cant. In 2020, the situation was reversed. Based on the essence of indicator X_7, we can conclude that it can characterize both the economic and social components of regional development; that is, the interpretation of the results is not essentially affected by this indicator.

Table 4: Principal components' factor loadings values for data 2019 and 2020.

Indicators	Principal components			
	2019		2020	
	F_1	F_2	F_1	F_2
X_1	0.82	0.08	0.89	0.07
X_2	0.89	0.01	0.93	0.01
X_3	0.93	0.22	0.90	0.31
X_4	0.83	0.44	0.77	0.53
X_5	0.84	-0.25	0.87	-0.15
X_6	0.89	-0.13	0.93	-0.02
X_7	0.65	0.49	0.41	0.64
X_8	0.14	0.78	0.16	0.75
X_9	-0.25	-0.88	-0.21	-0.90

Table 5: Principal components' values for data 2019 and 2020.

Code	2019		2020	
	F_1	F_2	F_1	F_2
C_1	-0.55	0.49	0.04	0.53
C_2	1.31	-1.74	-0.02	-1.46
C_3	-6.03	-1.21	2.75	0.02
C_4	1.94	-3.29	-0.03	-2.32
C_5	0.90	0.38	-0.32	-0.11
C_6	1.59	-0.61	-0.70	-0.56
C_7	-1.98	-1.24	1.23	-0.58
C_8	0.42	0.29	-0.46	0.20
C_9	-4.30	0.56	1.13	1.24
C_10	1.25	-0.69	-0.10	-0.94
C_11	4.42	-0.63	-1.68	-1.16
C_12	-0.75	0.91	0.14	0.87
C_13	-0.92	-0.33	0.42	-0.16
C_14	-1.30	1.93	-0.08	2.09
C_15	-3.60	-1.78	2.25	-0.85
C_16	1.44	0.93	-0.75	0.42
C_17	0.47	0.92	-0.22	0.31
C_18	2.19	-0.49	-0.73	-0.67
C_19	-1.36	2.47	-0.07	1.84
C_20	1.14	0.51	-0.79	0.11
C_21	0.96	0.65	-0.47	0.42
C_22	0.09	0.40	-0.20	0.35
C_23	2.22	1.68	-1.28	0.65
C_24	0.44	-0.10	-0.07	-0.23

Graphic representations of the regions in the space of the identified principal components according to the data of 2019 and 2020 are respectively presented in figures 3 and 4.

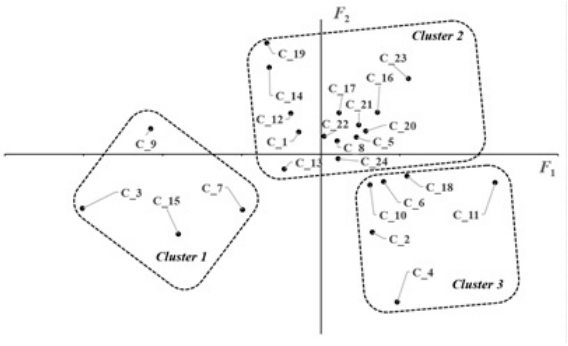

Figure 3: Grouping results of Ukraine's regions in the latent scale space for data 2019.

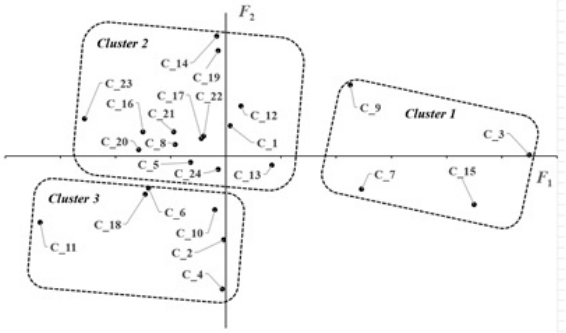

Figure 4: Grouping results of Ukraine's regions in the latent scale space for data 2020.

Figure 3 analysis allows us to conclude that we can also identify three clusters of regions. The resulting clusters in terms of content correspond to the formed clusters obtained by the k-means method. A similar situation occurs in figure 4. The results of a grouping of regions obtained using the principal components method are identical to those obtained from the clustering method.

However, it is worth noting. Figure 3 shows that cluster number 1 can be divided into at least two smaller clusters, including points C_7 (Zaporizhzhia region) and C_15 (Poltava region) to one of them and points C_3 (Dnipro region) and C_9 (Kyiv region) to the other. Similarly, points C_7 and C_15 can be allocated from cluster number 2 to a separate cluster. In the third cluster, we can distinguish points C_4 (Donetsk region) and C_11 (Luhansk region), which form two different clusters. So, the cluster structure may be more complex and require a more complex interpretation of the results. A similar situation occurs in figure 4.

However, according to the task, our study proceeded from a predetermined number of clusters. And the methods used in the study gave identical results.

5 CONCLUSIONS

Investment activity is always associated with a specific risk. Decision-making by potential investors requires a comprehensive study of the object of investment, mainly through the various assessments of the investment climate, business environment, and business conditions provided by multiple institutions. However, such estimates characterize the business environment of countries as a whole, while investors are usually interested in the separate territories and business units that are located there. Therefore, it is necessary to conduct a comprehensive analysis of the investment object to reduce the potential risks when investing. One of the approaches is to assess its investment attractiveness. For individual territorial entities, which are regions, it is advisable to determine the quantitative measures of the level of investment attractiveness and group them according to this indicator. This will identify regions with roughly the same investment climate. Given the significant multidimensionality of the description of the studied phenomenon, the solution of the grouping problem can be solved by applying the methods of multidimensional statistical analysis. In our study, we used the *k*-means method of clustering, which allowed us to divide the regions of Ukraine into relatively homogeneous groups according to the level of investment attractiveness.

Data for 2019 and 2020 were chosen for the study. These periods are characterized by the fact that at this time, the economy of Ukraine, like most other countries, came under the destructive influence of the COVID-19 pandemic. We limited ourselves to the selection of three clusters, which were given a meaningful interpretation: the first one is a cluster with regions that have a high level of investment attractiveness, the second cluster contains regions with a medium level of investment attractiveness, and the third cluster includes regions with a low level of investment attractiveness. Comparing clustering results for selected periods showed that the cluster structure of Ukrainian regions has not changed. To verify the correctness of the obtained grouping of regions, the regions of Ukraine were deployed in the space of latent indicators, which were calculated on the same data set by the method of principal components. A meaningful analysis of factor loads showed that one latent axis of the new space characterizes the economic component of investment attractiveness, and the other - is the social component. The results of grouping Ukraine's regions turned out to be identical to those obtained by the *k*-means method. It was also concluded that it would be more appropriate to allocate more clusters, which would provide a more accurate picture of the grouping of regions by the level of investment attractiveness. Such an assessment can be helpful for local governments, as they provide information on the relative level of investment attractiveness of a particular region compared to other territorial units and identify weaknesses in the areas of activity on which the assessment was based. Such results can be used to create and adjust regional socio-economic development programs, particularly in terms of planning to attract investment into the region's economy.

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Research of Inflation Processes in Ukraine in Crisis Conditions

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Abstract: The purpose of the article is a research of the level of inflation in Ukraine based on the analysis of the dynamics of the annual consumer price index. In connection with the crisis phenomena in the economy, which are the consequences of the COVID-19 pandemic and Russian military aggression, the problem of restraining excessive price growth becomes the most important condition for the implementation of the socio-economic and monetary policy of the state. The impact of macroeconomic indicators such as gross domestic product, the hryvnia exchange rate against the US dollar, and the average wage in Ukraine on the growth of consumer prices is studied. With the use of application packages, it is substantiated that the dynamics of the consumer price index is characterized by a random component and cannot be approximated by elementary functions that depend only on time. With the help of MS Excel spreadsheets, a mathematical model of the dependence of the consumer price index on the rates of growth and decline of the main macroeconomic indicators was built in the form of a multiple regression equation and its adequacy was proven. Based on the constructed model, it was concluded that the exchange rate of the national currency has the greatest influence on the consumer price index. The results of the study can be used in forecasting the annual inflation rate for the next period. Forecasting of the consumer price index for 2022 was made based on the constructed model.

1 INTRODUCTION

The coronavirus pandemic and the quarantine restrictions aimed at containing it have had a negative impact on the global and domestic economy. The beginning of 2022 shocked the whole world with the open military aggression of the Russian regime, which led to crisis phenomena in Ukraine and the world. At the current stage, one of the most urgent problems is the prevention of excessive price growth. In macroeconomics, the situation in Ukraine is called stagflation. Stagflation is characterized by rising prices during crisis phenomena in the economy. The implementation of measures to support a stable level of inflation becomes the most important condition for the implementation of the monetary policy of the state.

In the research, inflationary processes are studied on the basis of the annual consumer price index (CPI) in Ukraine for the period from 2002 to 2021 according to the official website of the State Statistics Service (SSSU, 2022). The consumer price index demonstrates the general level of inflation in the economy and is an indicator of the population's standard of living and social-economic development. The CPI takes place in a center of the indicators of price statistics system and is calculated in Ukraine, starting from August 1991, as part of the program for developing a number of macroeconomic indicators based on international standards. The CPI has become an important economic indicator since its introduction. The value of the CPI is difficult to overestimate, as it directly or indirectly affects the standard of living of the country's population (State Statistics Service of Ukraine, 2022). To curb excessive price growth, the mathematical modeling of the level of inflation based on a scientific analysis of the dynamics of the cost of goods and services, the volume of GDP, the exchange rate of the domestic currency, the level of wages and other macroeconomic factors are needed.

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2 PROBLEM STATEMENT AND SOLUTIONS

Considering the impact of inflation on socio-political and economic life, various aspects of its research are presented in the works of many domestic and foreign scientists. The mutual influence of the growth of consumer prices and inflationary expectations in Ukraine was studied in the work of Khokhych (Khokhych, 2020). In the work of Gitis et al. (Gitis et al., 2020), the problem of the impact of rising consumer prices on the level of income of the population is raised. In the article by Kuzheliev et al. (Kuzheliev et al., 2020), the impact of inflation and other monetary policy instruments on key economic indicators in Ukraine during periods of stability and crisis is considered.

Sarel (Sarel, 1996) analyzed the possibility of a nonlinear impact of the CPI on economic growth, when this indicator is critical – 108. Below this value, the CPI does not affect growth, or may even have a slightly positive effect.

In the works of Macovei and Scutaru (Macovei and Scutaru, 2016; Macovei, 2020), the influence of the consumer price index on the economic growth of Romania was investigated on the basis of annual data from 1991 to 2018 and it was proposed to use a nonlinear regression model. The results of the study show a close relationship between the consumer price index (CPI) and the gross domestic product (GDP).

The analysis of the use of the value unit index for curbing inflation in Latin American countries was carried out by Yereshko and Hafarov (Yereshko and Hafarov, 2020).

Shinkarenko et al. (Shinkarenko et al., 2021) examines the behavior of the consumer price index in Ukraine for the period from January 2010 to September 2020 by month. The characteristics of the initial time series, the analysis of auto-correlation functions made it possible to reveal the trend of their development and the presence of annual seasonality. To simulate the behavior of the consumer price index and forecast for the following months, 2 types of models were used: the additive ARIMA*ARIMAS model, better known as the Box-Jenkins model (Box et al., 2015) and the exponential smoothing model with Holt-Winters seasonality estimation (Gardner Jr., 1985). As a result of using the STATISTICA package, the most adequate models reflecting the monthly dynamics of the consumer price index in Ukraine were built. However, the rapid deterioration of the economic situation in Ukraine in connection with open Russian military aggression does not allow the application of these models.

3 MAIN RESULTS

Inflationary processes are studied on the basis of the following macroeconomic indicators: the annual consumer price index in Ukraine (CPI), the annual gross domestic product (GDP) calculated in US dollars, the exchange rate of the hryvnia against the US dollar (HR) and the level of average wages (AW), converted in US dollars for the period from 2002 to 2021. The array of data was compiled on the basis of the reports of the State Statistics Service of Ukraine (SSSU, 2022) and the National Bank of Ukraine (NBU, 2022). The resulting array of data is shown in table 1.

To build a model and forecast the level of inflation, we first find the main statistical characteristics of the dynamic series under investigation. They are shown in table 2.

Numerical characteristics of the CPI range show that the consumer price index fluctuated in the interval from 99,4% to 143,3% during the studied period. The mean square deviation of 6,63 shows that the variation of the consumer price index for the studied period is quite small.

The characteristics of the GDP series show that during the studied period the volume of the gross domestic product gradually increased from 50 133 million US dollars to 183 310 million US dollars. The mean square deviation of 32130,572 indicates the absence of anomalous values of the indicator except for certain years.

The statistics of the HR series show a gradual depreciation of the national currency from 5,05 to 27,2 per US dollar. The mean square deviation of 8,344 shows that hryvnia exchange rate jumps in some years were quite insidious.

Numerical characteristics of a number of wage earners show that the average wage in Ukraine gradually increased from USD 70,59 to USD 430,21. The mean square deviation of 83,025 indicates that the growth of the indicator occurred gradually.

In order to clearly display the dynamics of the consumer price index in Ukraine during 2002-2021, a diagram of the indicator was constructed (figure 1).

The constructed trend equation shows that CPI forecasting using standard time series forecasting methods is not possible, as the correlation coefficient is very small. The series has neither a trend nor a seasonal component, therefore, in order to make an adequate forecast, it is necessary to identify the factors that have the greatest influence on the dynamics of the CPI.

Since the indicators chosen for the model have fundamentally different dimensions, it is impossible

Table 1: Some macroeconomic indicators in Ukraine for 2002-2021.

Years	CPI	GDP	HR	AW	CPI	GDP	HR	AW
2002	99,4	59286	5,29	70,59	-	-	-	-
2003	108,2	50133	5,33	86,74	1,082	1,183	0,992	1,229
2004	112,3	64883	5,32	111,02	1,123	1,294	0,997	1,280
2005	110,3	86142	5,12	157,3	1,103	1,328	0,963	1,417
2006	111,6	107753	5,05	206,51	1,116	1,251	0,985	1,313
2007	116,6	142719	5,05	267,87	1,166	1,325	1,000	1,297
2008	122,3	179992	5,27	343,43	1,223	1,261	1,043	1,282
2009	112,3	117228	7,79	245,05	1,123	0,651	1,479	0,714
2010	109,1	136419	7,94	283,12	1,091	1,164	1,019	1,155
2011	104,6	163160	7,97	331,24	1,046	1,196	1,004	1,170
2012	99,8	175781	7,99	379,42	0,998	1,077	1,003	1,145
2013	100,5	183310	7,99	409,59	1,005	1,043	1,000	1,080
2014	124,9	131805	11,89	292,32	1,249	0,719	1,487	0,714
2015	143,3	90615	21,84	162,60	1,433	0,687	1,838	0,556
2016	112,4	93270	25,55	203,02	1,124	1,029	1,170	1,249
2017	113,7	112154	26,60	267,16	1,137	1,202	1,041	1,316
2018	109,8	130832	27,20	325,99	1,098	1,167	1,023	1,220
2019	104,1	153781	25,85	406,40	1,041	1,175	0,950	1,247
2020	105,0	155568	26,96	430,21	1,050	1,012	1,043	1,059
2021	110,0	200090	28,78	506,42	1,100	1,286	1,068	1,177

Table 2: Characteristics of dynamic series for 2002-2021.

Indicator	Average value	Average deviation	Minimal value	Maximal value
CPI	112,3	6,630	99,4	143,3
GDP	126419,1	32130,572	50133	183310
HR	13,2	8,344	5,05	27,20
AW	272,7	83,025	70,59	430,21

to build a function that will accurately reflect the impact of GDP, HR and SP on the CPI. In such cases, it is necessary to standardize the data. Methods of standardization of research factors are described in detail in works (Shinkarenko et al., 2019; Matskul et al., 2020). The method of eliminating different dimensions is also used, which is based on the comparison of growth rates of time series (for example, (Kozak et al., 2017)). This is what we used in our work to analyze inflationary processes.

When modeling relationships in dynamic series, relative values are widely used. This is due to their greater elasticity in time compared to absolute values. In addition, it helps eliminate multicollinearity and autocorrelation of the residuals. We will assume that the CPI is modeled by a function of the Cobb-Douglas-Tinbergen type (Yankovoy and Yankovoy, 2019):

$$I = \gamma \cdot Q^{\alpha} \cdot G^{\beta} \cdot K^{\lambda} \cdot e^{\mu t}. \quad (1)$$

where I is the consumer price index (%), Q is GDP (millions of US dollars),G is the hryvnia exchange rate (US dollars), K is the average wage (US dollars). Parameters α, β, γ and μ are elasticity coefficients: α characterizes the increase in the CPI per unit of GDP growth at unchanged HR and SP, β is the increase in CPI per unit of increase in HR at unchanged GDP and SP, Λ is the increase in CPI per unit of increase in SP at unchanged GDP and HR, μ — CPI growth due to factors not included in the model.

Applying logarithmic differentiation to the Cobb-Douglas-Tinbergen function, taking into account that each factor depends on time, we obtain a linear model that describes the relationship between growth rates:

$$i = \mu + \alpha \cdot q + \beta \cdot g + \lambda \cdot k. \quad (2)$$

where i, q, g, k are the growth rates of CPI, GDP, HR and AW, respectively. In the future, the rate of growth of the indicator will be understood as the ratio of its next level to the previous one. Note that this approach avoids reducing the indicators to one dimension. Table 1 shows the growth rates of each of the studied indicators.

To determine the general trend of the behavior of the time series, a diagram was constructed that reflects the dynamics of the growth rates of the consumer

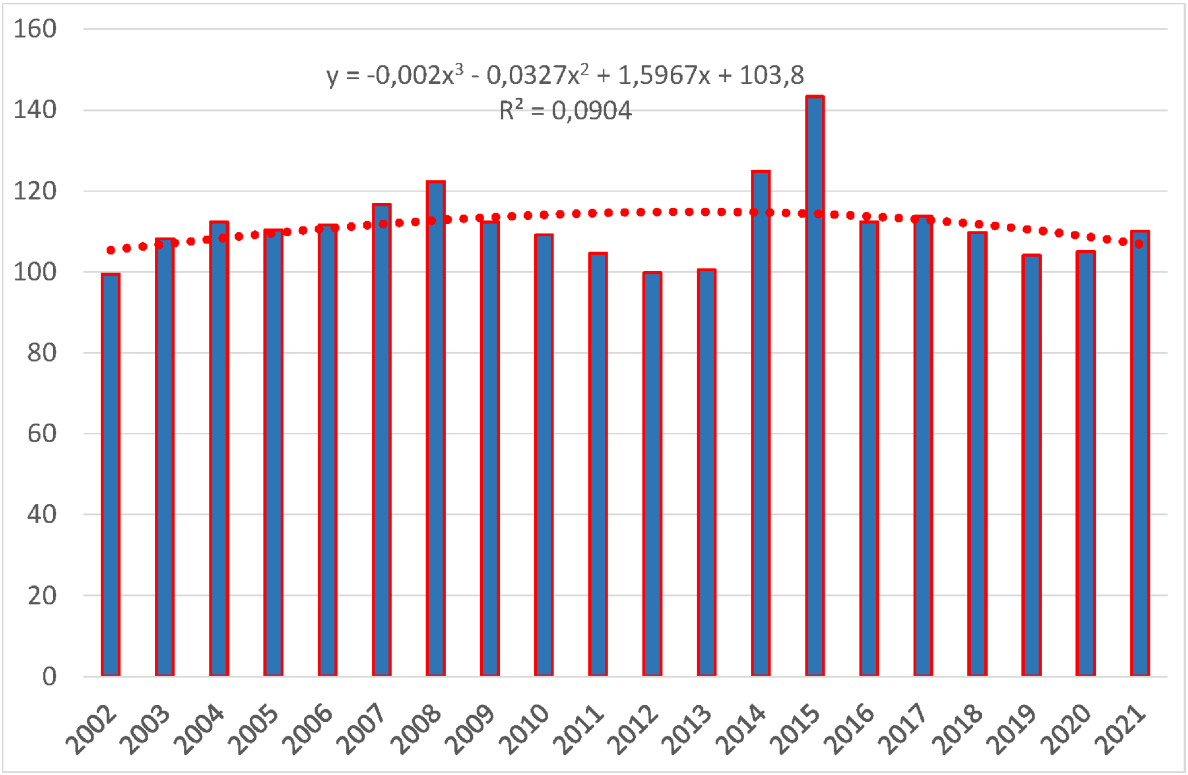

Figure 1: Dynamics of the consumer price index in Ukraine for 2002-2021.

price index, the gross domestic product, the hryvnia exchange rate, and the average wage (figure 2).

The analysis of the constructed trend lines shows that fluctuations in the level of the consumer price index are closely related to the behavior of the volume of the gross domestic product, the hryvnia exchange rate, and the average wage. To confirm the hypothesis about the presence of a close relationship between the specified factors, the correlation coefficients between the indicators were calculated. The obtained coefficients are shown in table 3.

Table 3: Correlation matrix of CPI, GDP, HR and AW.

	CPI	GDP	HR	AW
CPI	1	-0,43485	0,790091	-0,54429
GDP	-0,43485	1	-0,87949	0,954285
HR	0,790091	-0,87949	1	-0,91172
AW	-0,54429	0,954285	-0,91172	1

The calculated coefficients allow us to conclude that the rate of growth of the consumer price index is most affected by fluctuations in the hryvnia exchange rate (a 1% devaluation of the hryvnia leads to an increase in the CPI by 0,79%). The influence of the growth rates of the gross domestic product and average wages is moderate and negative, that is, an increase in the GDP growth rate by 1% will lead to a decrease in the CPI by 0,43%, the consequence of an increase in the growth rate of GDP by 1% is a decrease in the CPI by 0,54%.

A regression equation was built using the MS Excel:

$$i = -0{,}335 + 0{,}545 \cdot q + 0{,}764 \cdot g + 0{,}007 \cdot k. \quad (3)$$

where i, q, g, k are the growth rates of CPI, GDP, HR and AW, respectively (figure 3).

The equation has good statistical indicators of correlation and regression analysis. The multiple correlation coefficient $R = 0{,}961$ shows that the volume of GDP, the hryvnia exchange rate and the average salary directly affect the change in the CPI (covering about 9% of the influencing factors). The standard error of the regression $S_y = 0{,}031$ is quite small, which indicates that the model corresponds to the economic process. The calculated value of the F-criterion is $F = 55{,}766$, its significance is $F = 4{,}97 \cdot 10^{-8}$. The calculated value is significantly less than 0,01, therefore, with a 99% level of reliability, it is possible to assert, according to Fisher's test, that the constructed model is adequate to the empirical data.

Let's check the reliability of each of the coefficients of the constructed equation: for the first coefficient

$$t_1 = 4{,}564, p_1 = 0{,}0004 < 0{,}005,$$

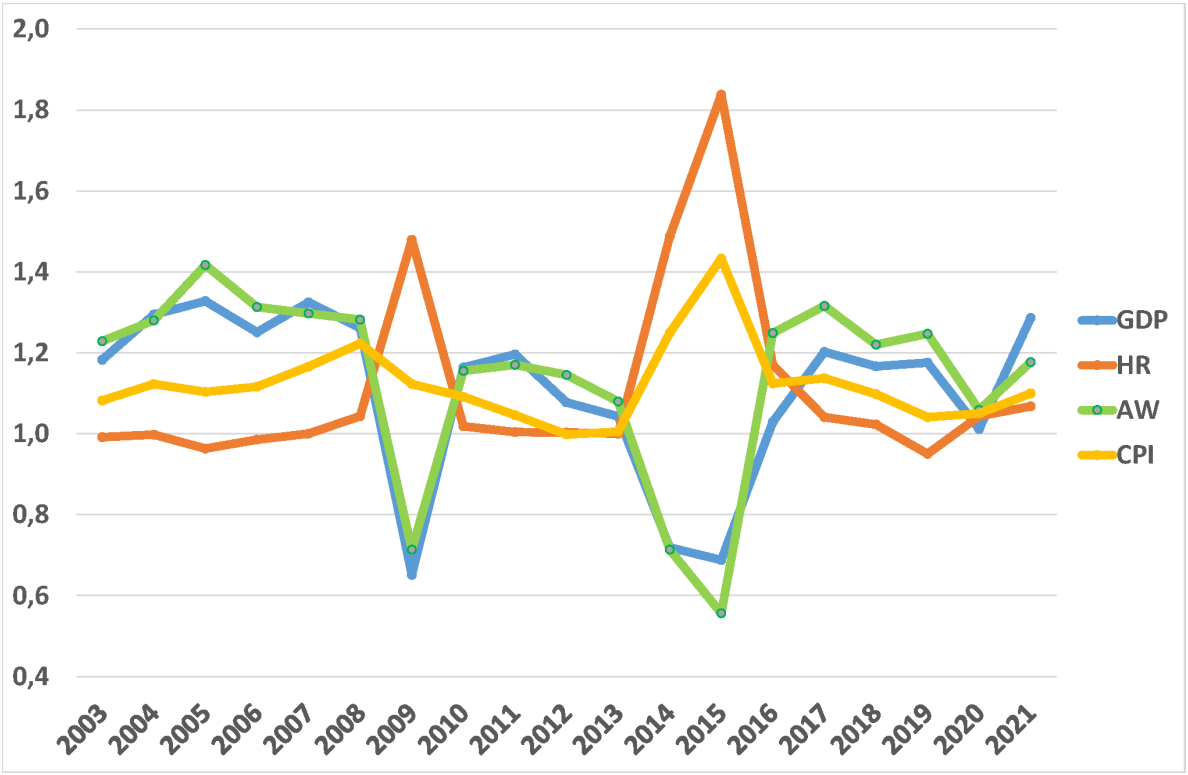

Figure 2: Growth rates of the CPI, GDP, HR and AW in Ukraine for 2003-2021.

RESULTS

Regression statistics	
R	0,960614201
R-square	0,922779642
Normalized R-square	0,906232423
standard error	0,031097824
Observations	19

Analysis of variance

	df	*SS*	*MS*	*F*	*Значимость F*
Regression	3	0,161790955	0,053930318	55,76644728	4,96759E-08
residual	15	0,013539045	0,000967075		
Total	18	0,17533			

	coefficient	standard error	*t-statistic*	*P-value*	
Y	-0,335	0,172	-1,949	0,072	
X1	0,545	0,119	4,564	0,000	
X2	0,764	0,077	9,954	0,000	
X3	0,007	0,124	0,055	0,957	

Figure 3: Results of Regression statistics and Analysis of variance.

therefore, according to the Student's criterion, the coefficient is statistically reliable with a level of 99%, for the second coefficient

$$t_2 = 0{,}077, p_2 = 9{,}89 \cdot 10^{-8} < 0{,}005,$$

therefore, according to the Student's test, the coefficient is statistically reliable at the 99% level, for the third coefficient the value

$$t_3 = 0{,}124, p_3 = 0{,}957 > 0{,}005,$$

therefore the coefficient is not statistically reliable at the 99% level. It is more likely that the problem arose as a result of the close connection between the factors of GDP and AW.

To check the reliability of the built model, we will calculate the forecast value of the consumer price index for the end of 2022, using the data on the gross domestic product, the hryvnia exchange rate and the average salary, which are given on the websites of the Cabinet of Ministers of Ukraine (Ministry of Finance of Ukraine, 2022) and the National Bank of Ukraine (NBU, 2022). According to the given data, a decrease in GDP is expected by 40%. The hryvnia exchange rate is set at UAH 40,0 per USD, up 38,7% from the previous period. The average salary at the end of 2022 is forecast to be UAH 18,535, which at the exchange rate of UAH 40,0 is 440,48 USD, the growth until 2021 is 12,9%. Let's calculate the predicted value of the CPI:

$$i = -0{,}335 + 0{,}545 \cdot 0{,}6 + 0{,}764 \cdot 1{,}39 + 0{,}007 \cdot 0{,}87 = 1{,}417. \quad (4)$$

The calculated value shows that the consumer price index in 2022 will increase by 41,7% compared to 2021.

4 CONCLUSION

The built mathematical model of the dependence of the growth of the index of social prices on the growth of the annual volume of the gross domestic product, the exchange rate of the hryvnia and the level of the average salary is adequate and reliable. Using the regression equation, it is possible to estimate the influence of factors on the change in the CPI and calculate the predicted values of the social price index.

The processing of the array of the consumer price index with the help of application programs proved that the indicator is characterized by a random component and cannot be approximated by elementary functions.

The forecast of the indicator for the end of 2022 showed that, taking into account the crisis in the economy associated with the Russian military aggression, a significant increase in the level of inflation is expected in Ukraine.

For a more detailed study of the causes and rates of growth of the consumer price index, one should consider the change in the value of its individual components (food, non-food, services and other groups of goods), the relationship of the indicator with a similar indicator in neighboring countries (price growth on the world market), the influence of the state debt to the level of inflation in the country.

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Sentiment Analysis of Electronic Social Media Based on Deep Learning

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Abstract: This paper describes Deep Learning approach of sentiment analyses which is an active research subject in the domain of Natural Language Processing. For this purpose we have developed three models based on Deep Neural Networks (DNNs): Convolutional Neural Network (CNN), and two models that combine convolutional and recurrent layers based on Long-Short-Term Memory (LSTM), such as CNN-LSTM and Bi-Directional LSTM-CNN (BiLSTM-CNN). As vector representations of words were used GloVe and Word2vec word embeddings. To evaluate the performance of the models, were used IMDb Movie Reviews and Twitter Sentiment 140 datasets, and as a baseline classifier was used Logistic Regression. The best result for IMDb dataset was obtained using CNN model (accuracy 90.1%), and for Sentiment 140 the model based on BiLSTM-CNN showed the highest accuracy (82.1%) correspondinly. The accuracy of the proposed models is a quite acceptable for practical use and comparable to state of the art models.

1 INTRODUCTION

The rapid development of electronic mass media and social networks has given a new impetus to the development of automated Natural Language Processing (NLP) systems.

NLP is an interdisciplinary field at the intersection of Computer Science, Artificial Intelligence and Linguistics, dedicated to how computers analyze natural (human) language models.

The range of tasks that NLP solves is quite wide. For example, NLP can be used to build automatic systems like machine translation, speech recognition, named entity recognition, text classification and summarization, sentiment analysis, question answering, autocomplete, predictive text input, and so on (N1, 2021; Mayur et al., 2022; N43, 2018).

One of the important tasks of NLP is Sentiment Analysis (SA), also known as opinion mining. SA is an attempt to extract subjective characteristics from the text: emotions, sarcasm, confusion, suspicion etc.

The main goal of SA is to classify the polarity of a given document, and to determine whether the opinion expressed in a document or sentence is positive, negative, or neutral.

It is a very popular text classification technique because sentiment can convey a wealth of information about one's point of view on a subject under discussion. It helps to conduct a comprehensive analysis of feedback, polarity of messages or reactions. SA is widely used among businessmen, marketers and politicians.

In the analysis of public opinion on sensitive social and political issues, identifying common themes and tone of discussion can greatly simplify the work of experts in the field of sociology, political science and journalism (Iglesias and Moreno, 2020; Pozzi et al., 2016).

Due to the permanent increase in the amount of information, previously developed technologies lose their effectiveness. The ability to quickly monitor and control public opinion is still the key to success.

Traditionally, this problem has been solved by dictionary or rule-based approaches (Karamollaoğlu et al., 2018; Dhaoui et al., 2017; Khoo and Johnkhan,

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2018; Alessia et al., 2015). These approaches are statistical methods that use pre-assembled sentiment dictionaries containing different words and their corresponding polarities for determining a given word as "positive" or "negative".

However, construction complete dictionaries for a large amount of unstructured data generated by modern electronic media and social networks are quite a tedious task.

Machine Learning (ML) methods help solves this problem. Such approaches are based on algorithms for classifying words according to the corresponding sentiment marks. That's why ML models are preferred for SA due to their ability to processing with the large amount of texts compared to dictionary-based approaches.

In recent decade, Deep Neural Networks (DNNs) have been actively used to solve many NLP tasks, including SA (Li, 2017; Trisna and Jie, 2022; Kamath et al., 2019). This became possible due to:

- the progress in designing DNNs of various architectures (recurrent, convolutional, encoder-decoder, transformer, hybrid);
- an increasing in computing performance, including through the use of graphics processors units and the availability of various cloud computing services;
- the creation of labeled datasets for various NLP tasks;
- development such models of pre-trained vector representations of words (word embedding) as Word2vec, FastText (Mikolov et al., 2013; Pennington et al., 2014; Bojanowski et al., 2017) which are available for many languages.

In the last few years, large pre-trained models based on the Transformer architecture and Attention mechanism such as GPT-3, BERT, ELMo etc. has had a significant impact in the solving of various NLP tasks (Durairaj and Chinnalagu, 2021; Geetha and Karthika Renuka, 2021; Deng et al., 2022; Tabinda Kokab et al., 2022). These models can be interpreted as language models which formed probability distributions over sequences of words.

Such models are universal and capable of "extracting" features from the text that are useful for solving many problems of text analysis. But they are quite "heavy", contain hundreds of millions parameters and require significant computational resources.

Therefore, for the most NLP practical applications, traditional approaches based on ML and Deep Learning (DL) have been successfully used.

The purpose of our research is to develop set models for sentiment classification based on different DNNs architecture and compare their performance on IMDb and Sentiment 140 Twitter datasets.

2 RELATED WORKS

Drus and Khalid (Drus and Khalid, 2019) provided a report of review on sentiment analysis in social media that explored the common methods and approaches which used in this domain. This review contains an analysis of about 30 publications published during 2014-2019 years. According to their results most of the articles applied opinion-lexicon method to analyses text sentiment in social media in such domain as world events, healthcare, politics and business.

Recently Jain et al. (Jain et al., 2021) published report on ML applications for consumer sentiment analysis in the domain of hospitality and tourism. This report based on 68 research papers, which were focused on sentiment classification, predictive recommendation decisions, and fake reviews detection.

They have shown a systematic literature review to compare, analyze, explore, and understand ML possibilities to find research gaps and the future research directions.

Sudhir and Suresh (Sudhir and Suresh, 2021) published comparative study of various approaches, applications and classifiers for sentiment analysis. They have discussed the advantages and disadvantages of the different approaches such as Rule-based, ML and DL approaches used for SA as well as compared the performances of the classification models on the IMDb dataset.

The authors note that, in general, ML-based approaches provide greater accuracy than Rule-based ones. At the same time, Conventional ML models (Support Vector Machine, Decision Trees, and Logistic Regression) provide classification accuracy at the level of 85-87% for the IMDb dataset. DL-based models (CNN, LSTM, GRU) shows higher accuracy: about 89% on the IMDb dataset.

Trisna and Jie (Trisna and Jie, 2022), presented a comparative review of DL approaches for Aspect-Based SA. The results of their analysis show that the use of pre-trained embeddings is very influential on the level of accuracy. They also found that every dataset has a different method to get better performance. It is still challenging to find the method that can be flexible and effective for using in several datasets.

There are several papers devoted to developing new methods of word embeddings.

Thus, Biesialska et al. (Biesialska et al., 2021) proposed a novel method which uses contextual em-

beddings and a self-attention mechanism to detect and classify sentiment. They performed experiments on reviews from different domains, as well as on languages (Polish and German).

Authors have shown that proposed approach is on a par with state-of-the-art models or even outperforms them in several cases.

Rasool et al. (Rasool et al., 2021) proposed a novel word embedding method novel word-to-word graph (W2WG) embedding method for the real-time sentiment for word representation. He noted that performance evaluation of proposed word embedding approach with integrated LSTM-CNN outperformed the other techniques and recently available studies for the real-time sentiment classification.

Recently have been published several research papers devoted using DNNs different architecture based on CNN-LSTM models for SA task (Elzayady et al., 2021; Hernández et al., 2022; Khan et al., 2022; Priyadarshini and Cotton, 2021; Haque et al., 2020).

Elzayady et al. (Elzayady et al., 2021) presented two powerful hybrid DL models (CNN-LSTM) and (CNN-BILSTM) for reviews classification. Experimental results have shown that the two proposed models had superior performance compared to baselines DL models (CNN, LSTM).

Khan et al. (Khan et al., 2022) evaluated the performance of various word embeddings for Roman Urdu and English dialects using the CNN-LSTM architecture and compare results with traditional ML classifiers. Authors mentioned that BERT word embedding, two-layer LSTM, and SVM as a classifier function are more suitable options for English language sentiment analysis.

Priyadarshini and Cotton (Priyadarshini and Cotton, 2021) proposed a novel LSTM-CNN grid search-based DNN model for sentiment analysis. As to the experimental results they observed proposed model performed relatively better than other algorithms (LSTM, Fully-connected NN, K-nearest neighbors, and CNN-LSTM) on Amazon reviews for sentiment analysis and IMDb datasets.

Haque et al. (Haque et al., 2020) analyzed different DNNs for SA on IMDb Movie Reviews. They have compared between CNN, LSTM and LSTM-CNN architectures for sentiment classification in order to find the best-suited architecture for this dataset. Experimental results have shown that CNN has achieved an $F1-score$ of 91% which has outperformed LSTM, LSTM-CNN and other state-of-the-art approaches for SA on IMDb dataset.

Quraishi (Quraishi, 2020) evaluated of four ML algorithms (Multinomial Naïve Bayes, Support Vector Machine, LSTM, and GRU) for sentiment analysis on IMDb review dataset. He found that among these four algorithms, GRU performed the best with an accuracy of 89.0%.

Derbentsev et al. (Derbentsev et al., 2020) also explored the performance of four ML algorithms (Logistic Regression, Support Vector Machine, Fully-connected NN, and CNN) for SA on IMDb dataset. They used two pre-trained word embeddings GloVe and Word2vec with different dimensions (100 and 300) as well as TF-IDF representation. They reported that the best classification accuracy (90.1%) was performed by CNN model with Word2vec-300 embedding.

3 BASE CONCEPT OF NLP APPLYING TO SENTIMENT ANALYSIS

3.1 ML Approach of NLP

To solve NLP problems using ML methods, it is necessary to represent the text in the form of set feature vectors. The text can consist of words, numbers, punctuation, special characters of additional markup (for example, HTML tags). Each such "unit" can be represented as a vector in various ways, for example, using unitary codes (one-hot encoding), or context-independent (depended) vector representations.

The base idea of applying ML to NLP was introduced by Bengio et al. (Bengio et al., 2003). They proposed to jointly learn an "embedding" of words into an n-dimensional numeric vector space and to use these vectors to predict how likely a word is given its context.

In the case of text, features represent attributes and properties of documents including their content and meta-attributes, such as document length, author name, source, and publication date. Together, all document features describe a multidimensional feature space to which ML methods can be applied.

Thus, in the most general terms, the application of ML to SA problems consists of the following: text data preprocessing, feature extraction, classification, and interpretation of results.

3.2 Data Pre-Processing

The quality of the result depends on the input data. Therefore, it is important that they are prepared in the best possible way. In general, pre-processing stage consists of the following steps (Brownlee, 2017;

Hobson et al., 2019; Camacho-Collados and Pilehvar, 2018):

- Text cleaning. First of all, we need to clean up the text. Depending on the task, cleaning includes removing non-alphabets, various tags, URLs, punctuation, spaces, and other markup elements;
- Segmentation and tokenization. They are relevant in the vast majority of cases, and provide division of the text into separate sentences and words (tokens). As a rule, after tokenization all words are converted to lower case;
- Lemmatization and stemming. Typically, texts contain different grammatical forms of the same word, and there may also be words with the same root. Lemmatization is the process of reducing a word form to a lemma - its normal (dictionary) form. Stemming is a crude heuristic process that cuts off "excess" from the root of words, often resulting in the loss of derivational suffixes. Lemmatization is a subtler process that uses vocabulary and morphological analysis to eventually reduce a word to its canonical form, the lemma;
- Definition of context-independent features that characterize each of the token, which not dependent on adjacent elements;
- Refining significance and applying a filter to stop words. Stop words are frequently used words that do not add additional information to the text. When we apply ML to texts, such words can add a lot of noise, so it is necessary to get rid them;
- Dependency parsing. The result is the formation of a tree structure, where the tokens are assigned to one parent, and the type of relationship is established;
- Converting text content to a vector representation that highlights words used in similar or identical contexts.

3.3 Features Extraction

ML algorithms cannot work directly with raw text, so it is necessary to convert the text into sets of numbers (vectors) – construct a vector representation. In ML this process is called feature extraction.

Vector representation is a general name for various approaches to language modeling and representation training in NLP aimed at matching words (and possibly phrases) from some dictionary of vectors.

The most common approaches for construction vector representations are Bag of Words, TF-IDF, and Word Embeddings (Hobson et al., 2019).

3.3.1 Bag of Words

Bag of words (Bow) is a popular and simple feature extraction technique used in NLP. It describes the occurrences of each word in the text.

Essentially, it creates a matrix of occurrences for a sentence or document, ignoring grammar and word order. These frequencies ("occurrences") of words are then used as features for learning.

The basic idea of applying Bow is that similar documents have similar content. Therefore, basis on content, we can learn something about the meaning of the document.

For all its simplicity and intuitive clarity, this approach has a significant drawback. The Bow encoding uses a corpus (or set, collection) of words and represents any given text with a vector of the length of the corpus. If a word in the corpus is present in the text, the corresponding element of the vector would be the frequency of the word in the text.

If individual words are encoded by one-hot vectors, then the feature space will have a dimension equal to the cardinality of the collection's dictionary, i.e. tens or even hundreds of thousands. This dimension rises along with the increasing of the amount of dictionary.

3.3.2 N-Grams

Another, more complex way to create a dictionary is to use grouped words. This will resize the dictionary and give Bow more details about the document.

This approach is called "N-gram". An N-gram is a sequence of any entities (words, syllable, letters, numbers, etc.). In the context of language corpora, an N-gram is usually understood as a sequence of words.

A unigram is one word, a be-gram is a sequence of two words, a trigram is three words, and so on. The number N indicates how many grouped words are included in the N-gram. Not all possible N-grams get into the model, but only those that appear in the corpus.

3.3.3 TF-IDF

Term Frequency (TF) is the ratio of the number of appearing a certain word to the total number of words in the document. Thus, the importance of a word t within a single document d_i is evaluated:

$$TF(t,d_i) = \frac{n_t}{\sum_k n_k}, \tag{1}$$

where n_t is the number of occurrences of the word t in the document d_i, and in the denominator of the fraction is the total number of words in the document.

But frequency scoring has a problem: words with the highest frequency have, accordingly, the highest score. There may not be as much information gain for the model in these words as there is in less frequent words.

One way to remedy the situation is to downgrade a word that appears frequently in all similar documents. This metric is called $TF-IDF$ (short for Term Frequency – Inverse Document Frequency).

In this metric IDF is the inverse of the frequency with which a certain word occurs in the documents of the collection:

$$IDF(t,d_i,D) = \log \frac{|D|}{|\{d_i \in D | t \in d_i\}|}. \quad (2)$$

Here $|D|$ is the number of documents in the collection (corpus), $\{d_i \in D | t \in d_i\}$ is the number of documents in the collection D that contain word t.

There is only one IDF value for each unique word within a given collection of documents. IDF metric reduces the weight of commonly corpusused words.

$TF-IDF$ is a statistical measure for estimating the importance of a word in a document that is part of a collection or corpus:

$$TF\text{-}IDF(t,d_i,D) = TF(t,d_i) \times IDF(t,d_i,D). \quad (3)$$

$TF-IDF$ scoring increases in proportion to the frequency of occurrence of the word in the document, but this is compensated by the number of documents containing this word.

The disadvantage of the frequency approach based on this metric is that it does not take into account the context of a single word. Moreover, it does not distinguish the semantic similarity of words. All vectors are equally far from each other in the feature space.

3.3.4 Word Embedding

Word embedding is one of the most popular representations of document's vocabulary. This is a technique that maps words into number vectors, where words which have similar meanings will be close to each other with their vector representation in terms of some distance metric in the vector space.

Word embedding gives the impressive performance of DL methods on challenging NLP problem. Recently, several powerful word embedding models have been developed:

- Word2vec (short from Words to Vectors, provided by Google in 2013 (Mikolov et al., 2013);
- GloVe (short from Global Vectors, provided by Stanford University in 2014 (Pennington et al., 2014);
- FastText (provided by Facebook in 2017 (Bojanowski et al., 2017);
- BERT (short from Bidirectional Encoder Representations from Transformers, provide by Google in 2018 (Devlin et al., 2018).

These models are pre-trained on large corpuses of texts, including Wikipedia and specific domain.

Word2vec is a set of ANN models designed to obtain word embedding of natural language words. It takes a large text corpus as input and maps each word to a vector, producing word coordinates as output. It first generates a dictionary of the corpus and then calculates a vector representation of the words by learning from the input texts.

The vector representation is based on contextual proximity: words that occur in the text next to the same words (and therefore have a similar meaning) will have close (by cosine distance) vectors.

Word2vec implements two main learning algorithms: CBoW (Continuous Bag of Words) and Skip-gram (figure 1).

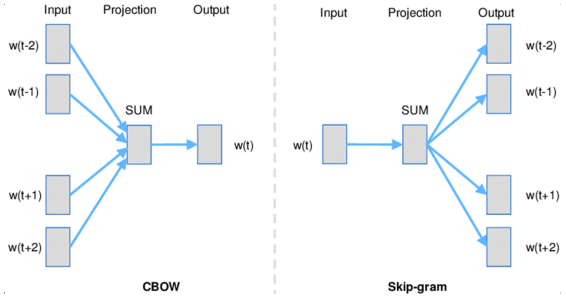

Figure 1: Simplified representation of the CBoW and Skip-gram models (Mikolov et al., 2013).

CBoW is an architecture that predicts the current word based on its surrounding context. Architecture like Skip-gram does the opposite: it uses the current word to predict surrounding words.

Building a Word2vec model is possible using these two algorithms. The word order of the context does not affect the result in any of these algorithms.

GloVe focuses on words co-occurrences over the whole corpus. Its embeddings relate to the probabilities that two words appear together. So, GloVe combines features of Word2vec and singular co-occurrence matrix decomposition.

In the present study, we applied both Word2vec and GloVe models to obtain vector representations of words.

The main application effect of using pre-trained language models is to obtain high-quality vector representations of words that take into account contextual dependencies and allow you to achieve better results on targets.

4 DNNs Classification Models Design

After previous stage, we can start building a classification model. The model type and architecture depends on the research task of SA which can be performed at different hierarchical levels of text documents (document-level, sentence-level, word or aspect-level), domains (reviews about travel agencies, hotels, movies, election opinion prediction, analysis of public opinion on acute social and political issues), binary or multiclass classification.

If we have a dataset of texts with class labels (for example, with binary labels "positive" and "negative"), we could apply Supervised ML techniques, in particular, binary classification algorithms.

Mathematically, this problem can be formulated as follows: given training sample of texts $X = \{x_1, x_2, ...x_m\}$, for each text there is a class label $Y = \{y_i\}$, $y_i \in \{0,1\}, i = 1,2,...m$.

It is necessary to build a classifier model $b(X,w): X \to Y$, where w is a vector of unknown parameters or weights.

At the same time, it is necessary to minimize the *Loss* function that determines the total deviation of real class labels from those predicted by the classifier. For binary classification problems, the most common is binary cross-entropy:

$$Loss = -\frac{1}{N}\left[\sum_{i=1}^{N}(y_i \log(p_i) + (1-y_i)\log(1-p_i))\right] \quad (4)$$

where N is the size of the training sample, $y_i = \{0,1\}$ is the true class label for the i-th data sample, p_i is the probability of belonging to the positive class for the i-th data sample provided by the classifier.

4.1 Logistic Regression

Since the task of SA in the general case is reduced to the binary classification problem (negative, positive), we chose the Logistic Regression (LR) model as the baseline classifier $b(\cdot)$:

$$b(X,w) = \sigma(\langle w,x\rangle), \quad (5)$$

where $\langle w,x\rangle$ - denotes the scalar product, $\sigma(\cdot)$ is a *Sigmoid* (logistic) function

$$\sigma(z) = \frac{1}{1+\exp(-z)}. \quad (6)$$

LR has such advantage as it can be used to predict the probability to belong a training sample (in our case, tokenized and vectorized text) to one of the two target classes.

4.2 CNN Model

CNNs are a class of DNNs that were originally designed for image processing (LeCun and Bengio, 1998). But these models have shown their efficiency for many other tasks, such as time series forecasting (LeCun et al., 2015).

Kim (Kim, 2014) has shown that CNNs are efficient for classifying texts on different datasets. Recently, they have also been used for various NLP tasks (speech generation and recognition, text summarization, named entity extraction).

The architecture of CNNs consists of convolutional and subsampling layers (figure 2).

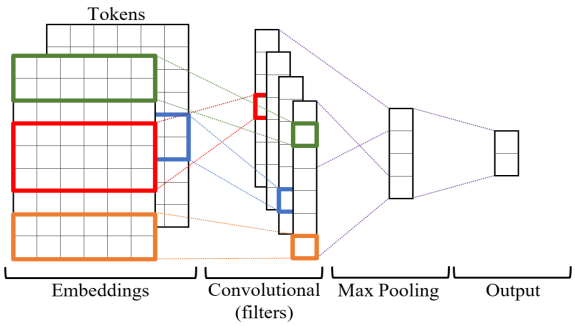

Figure 2: Convolutional Neural Network (CNN) Architecture for Text Processing (Kim, 2014).

The convolutional layer performs feature extraction from the input data and generates feature maps. The feature map is computed through an element-wise multiplication of the small matrix of weights (kernel) and the matrix representation of the input data, and the result is summed.

This weighted sum then passed through the non-linear activation function. One of the most common is the function *ReLu*, which is given as $ReLu(x) = \max(0,x)$.

The pooling (subsampling) layer is a non-linear compaction of the feature maps. For example, max-pooling takes the largest element from the feature map and extracts the sum of all its elements.

After max-pooling, feature maps are concatenated into a flatten vector, which will then be passed to a fully connected layer.

The input data for the most NLP problems is text which consists of sentences and words. So we need represent the text as an array of vectors of a certain length: each word mapped to a specific vector in a vector space composed of the entire vocabulary.

As these vectors, we can use word frequencies (for example, obtained using the $TF-IDF$ metric), or pre-trained embeddings (Word2vec, GloVe, FastText).

Unlike images processing, text convolution is performed using one-dimensional filters (1D Convolution) on one-dimensional input data, for example, sentences, using convolution kernels of different size (widths).

Applying of multiple kernels widths and feature maps is analogous to the use of N-grams.

For image processing, convolutions are usually performed on separate channels that correspond to the colors of the image: red, green, blue. Set of different filters is applied for each channel, and the result of this operation is then merged into a single vector.

For text processing as channels we can consider, for example, the sequence of words, or words embeddings. Then different kernels applied to the words can be merged into a single vector.

The final result of sentiment analysis is obtained by applying *Sigmoid* activation function (binary classification task) or *Softmax* (in the case of multi-class task).

4.3 LSTM and BiLSTM Model

Sequential information and long-term dependencies in NLP traditionally performed with Recurrent Neural Networks (RNNs) which could compute context information, for example, in dependency parsing.

The most common and efficient for many ML tasks, including NLP, were architectures based on LSTM (Long Short Term Memory) or GRU (Gated Recurrent Unit) cells (Brownlee, 2017; Kamath et al., 2019).

4.3.1 LSTM

LSTM model proposed by Hochreiter and Schmidhuber (Hochreiter and Schmidhuber, 1997) introduces the concept of a state for each of the layers of a RNN which plays the role of memory.

The input signal affects the state of the memory, and this, in turn, affects the output layer, just like in a RNN. But this state of memory persists throughout the time steps of a sequence (for example, time series, sentence, or text document). Therefore, each input signal affects the state of the memory as well as the output signal of the hidden layer.

LSTM cell includes several units or gates: the inputs, output, and forget gates (figure 3). These gates are used to control a memory cell that is carrying the hidden state h_t to the next time step.

The LSTM cell is formally defined as:

$$f_t = \sigma(\mathbf{W}_f \cdot (h_{t-1}, \mathbf{x}_t) + b_f, \quad (7)$$

$$i_t = \sigma(\mathbf{W}_i \cdot (h_{t-1}, \mathbf{x}_t) + b_i, \quad (8)$$

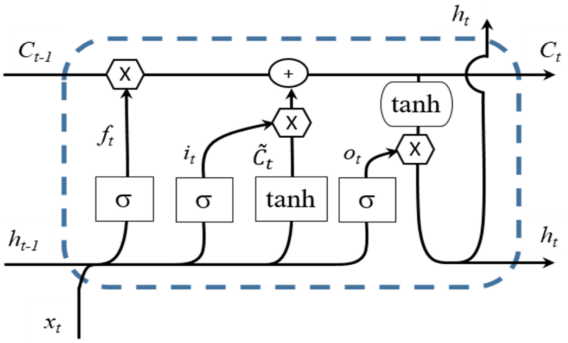

Figure 3: Diagram of a LSTM cell.

$$\tilde{C}_t = \tanh(\mathbf{W}_c \cdot (h_{t-1}, \mathbf{x}_t) + b_c), \quad (9)$$

$$o_t = \sigma(\mathbf{W}_o \cdot (h_{t-1}, \mathbf{x}_t) + b_o), \quad (10)$$

$$a_t = i_t \otimes \tilde{C}_t, \quad (11)$$

$$C_t = f_t \otimes C_{t-1} + a_t, \quad (12)$$

where $\mathbf{x}_t$ – is the vector of input sequence at time t; C_{t-1}, h_{t-1} – state (long-term content) and hidden state in previous time step $(t-1)$ respectively; $\sigma(\cdot)$, $\tanh(\cdot)$ are the *Sigmoid* and *Hyperbolic* tangent activation functions; $\otimes$ – the Kronecker product; $\mathbf{W}_f$, $\mathbf{W}_i$, $\mathbf{W}_o$ – the weight matrices for input, forget, output of the gates respectively; b_f, b_i, b_o – biases for the gates.

The *input gate* i_t determines which values need to update. Then the hyperbolic tangent layer builds a vector $\tilde{C}_t$ of new values that can be added to the state of the cell C_t.

The *forget gate* f_t controls how much is remembered (what part of the information is kept and what is erased) from step to step. Decision what information can be thrown out of the cell state is made by a sigmoid layer.

The *output gate* o_t receives an input signal (which is the concatenation of the input signal at time step t and the cell output signal at time step $(t-1)$ and passes it to the output. Thus, this gate determines which part of the long-term content C_t should be transferred to the next time step.

Each of these gates is a feed-forward neural network layer consisting of a sequence of weights fitted by the network with an activation function. This allows the network to learn the conditions for forgetting, ignoring, or keeping information in the memory cell.

Due its structure LSTM can learn and remember representations for variable length sequences, such as sentences, documents, and speech samples.

4.3.2 BiLSTM

Unidirectional (standard) LSTM only preserves information of the past because the only inputs it has

seen are from the past. Unlike standard LSTM, in BiLSTM (Bidirectional LSTM) model the input flows in both directions and it's capable of utilizing information from both sides.

So BiLSTM is a sequence processing model that consists of two LSTMs layers: one taking the input in a forward direction (from "past to future"), and the other in a backwards direction (from "future to past") (figure 4).

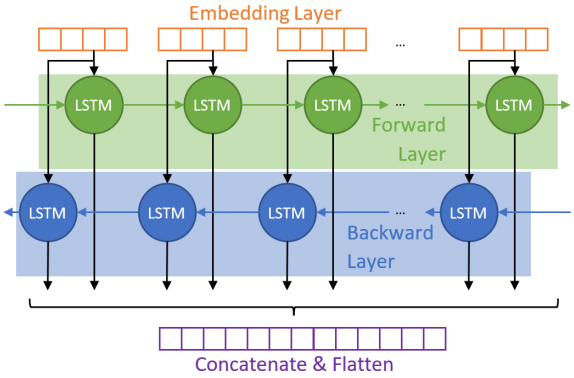

Figure 4: Diagram of a BiLSTM model.

For example, if we want to predict a word by context (the central word), the network takes a given number of words to the left of it as the context – the Forward layer performs it, as well as the words to the right of it – Backward layer performs it.

Then we can combine the outputs from both LSTM layers in different ways: as sum, average, concatenation or multiplication. This output contains the information or relation of past and future word.

BiLSTM increase the amount of information available to the network, improving the context.

It's also more powerful tool for modeling the sequential dependencies between words and phrases in both directions of the sequence than standard LSTM.

BiLSTM is usually used when we have the sequence to sequence tasks but it should be noted that BiLSTM (compared to LSTM) is a much "slower" model and requires more time for training.

4.4 CNN+LSTM Model

Both basic DNNs architectures CNN and LSTM have own advantages and disadvantages. Thus, LSTM networks can capture long-term dependencies and find hidden relationships in the data. CNNs are able to extract features using different convolutions and filters.

Therefore, the combination of convolutional and recurrent layers in the model turns out to be effective in many applied problem such as simulation of various natural processes, image processing, time series forecasting, and different NLP tasks (Chen and Wang, 2018; Derbentsev et al., 2021; Islam et al., 2020; Khan et al., 2022; Rasool et al., 2021; Shang et al., 2020).

So we developed two models based on modifications of CNN+LSTM architecture which final design and hyperparameters settings are given in the Section 6.

Our proposed models exploit the main features of both LSTM and CNN. In fact, LSTM could accommodate long-term dependencies and overcome the key issues with vanishing gradients. For this reason, LSTM is used when longer sequences are used as inputs. On the other hand, CNN appears able to understand local patterns and position-invariant features of a text.

5 DATASETS AND SOFTWARE IMPLEMENTATION

All developed DNNs (CNN, CNN-LSTM, BiLSTM-CNN), and LR as the baseline, were implemented in the Python 3.8 programming language using Scikit-learn library for LR, estimation classification accuracy, and for designing DNNs models we used Keras library and TensorFlow as backend.

We evaluate the performance of our models on two datasets: Stanford's IMDb dataset (Stanford's Large Movie Review Dataset), which contains 50,000 movie reviews as well as Sentiment 140 dataset (Kaggle, 2022) with 1.6 million tweets.

Both datasets are intended for binary classification: they contain for each text (review or tweet) a sentiment class binary label. They are also balanced, i.e. contain the same number of texts for the positive and negative classes.

6 EMPIRICAL RESULTS

6.1 Pre-Processing and Words Embeddings

For text pre-processing the Python library package NLTK (NLTK Project, 2022) was used, as well as customers regular expressions.

The pre-processing stage included removing punctuations, markup tags, html and tweet addresses, removing stop words and converting all words to lower case.

Tokenization was performed by using Keras preprocessing text library. After tokenization we got the length of the vocabulary in 92393 unique tokens for

IMDb dataset and 507702 for Sentiment140 respectively to which one token was added for representation out of vocabulary words.

It should be noted that the selected datasets are characterized by different average length of texts (number of words). Thus the length of most reviews does not exceed 500 words, and tweets – 50.

Since DNNs work with fixed-length input sequences we padded zero tokens all reviews and tweets which length are less than average to fixed length 500 and 50 words (tokens) respectively, and cut longer texts to these fixed sizes.

For words vector representation was used GloVe word embeddings with word vectors of dimension 100 provided by Gensim library (Řehůřek, 2022).

6.2 DNNs Models Design and Hiperparameters Setting

To initialize the weights of the first layer (Embedding Layer) for all models, pre-trained GloVe embeddings of size 100 were used. These weights were frozen and did not change during training.

The first model, CNN, consists of three sequential Convolutional layers with filter sets of different kernel widths. These layers are interspersed with Maxpooling layers. Behind them are a Flatten and a Fully connected (Dense) layer.

The second, CNN-LSTM model differs from the CNN by the presence of an LSTM layer instead of a Flatten after Convolutional and Maxpooling. The base idea of such architecture is that CNN can be used to retrieve higher-level word feature sequences and LSTM to catch long-term correlations across window feature sequences, respectively.

The third, BiLSTM-CNN model contains two BiLSTM layers (forward and backward), followed by a Convolutional and Maxpooling layers. After that, two Fully connected layers were used to reduce the output dimension and make prediction.

For all models Dropout layers were also used to prevent overfitting. As the *Loss*-function Binary Cross-Entropy (4) was chosen, which can be calculated as the average cross-entropy over all data samples (Geron, 2017).

The final parameters of DNNs architecture are shown in table 1.

6.3 Evaluating Performance Measures

The datasets were divided in the proportion of: 64% for training, 20% for validation, and 16% for test subsets respectively.

All DNNs models were trained over 5 epochs with a minibatch size of 256 and 1024 samples for IMDb and Sentiment 140 respectively. To compare classification performance of the developed models we used the *Accuracy* metrics given by:

$$Accuracy = \frac{TP+TN}{P+N} \times 100\%, \tag{13}$$

where TP and TN are the number of correctly predicted values of the positive and negative classes, respectively; P and N are the actual number of values for each of the classes.

We also calculated $F1$-*score* which is harmonic average between *Precision* (the percentage of objects in the positive class, which were classified as positive, are correctly classified), and *Recall* (percentage of objects of the true positive class which we correctly classified):

$$F1\text{-}score = \frac{2TP}{2TP+FP+FN}, \tag{14}$$

$$Precision = \frac{TP}{TP+FP}, \tag{15}$$

$$Recall = \frac{TP}{TP+FN}. \tag{16}$$

Here FP (False Positive) and FN (False Negative) are numbers of times (data samples) where the model incorrectly classified these samples as belonging to the positive and negative classes respectively.

The final results of classification performance are presented in tables 2-3.

Classification performance on IMDb dataset for all developed DNN models is better than baseline. The best *Accuracy* metric was obtained using the CNN model (90.09%). At the same time, models based on the combination of Convolutional and LSTM layers showed an *Accuracy* of 2-3% less (table 2).

It should be noted that obtained results are comparable or even superior in accuracy to the results given by other researchers (Haque et al., 2020; Quraishi, 2020; Ali et al., 2019) for IMDb dataset.

All models showed significantly lower accuracy (on average 10% less) on the dataset Sentiment 140 (table 3). The best result was achieved for the BiLSTM-CNN model – *Accuracy* 82.1%.

At the same time, the complication of models by adding new layers did not lead to a significant increase in accuracy, but prolonged the training time.

In our opinion, lower accuracy may be due to the fact that Sentiment 140 dataset contains many slang words that are out of vocabulary. So, if for IMDb dataset the part of the missing words was about 30 percent, then for the Sentiment 140 this part was more than 70.

Table 1: Final DNNs models hyperparameters setting.

Model	Layers	Parameters
CNN	Embedding	emb_dim 100, sent_len 500(50)
	Dropout	0.3
	Convolutional 1D	100 filters of size 2, act_func ReLu
	Max pooling	pool_size 2
	Convolutional 1D	100 filters of size 3, act_func ReLu
	Max pooling	pool_size 2
	Convolutional 1D	100 filters of size 4, act_func ReLu
	Max pooling	pool_size 2
	Flattent	
	Dropout	0.3
	Fully connected	1 neuron, act_func Sigmoid
CNN-LSTM	Embedding	emb_dim 100, sent_len 500(50)
	Dropout	0.3
	Convolutional 1D	50 filters of size 2, act_func ReLu
	Max pooling	pool_size 2
	Convolutional 1D	100 filters of size 2, act_func ReLu
	Max pooling	pool_size 2
	Convolutional 1D	200 filters of size 2, act_func ReLu
	Max pooling	pool_size 2
	LSTM	64 neurons, reccur_dropout 0.3
	Dropout	0.3
	Fully connected	32 neurons
	Fully connected	1 neuron, act_func Sigmoid
BiLSTM-CNN	Embedding	Emb_dim 100, sent_len 500(50)
	Dropout	0.3
	Bidirectional	LSTM with 100 neurons
	Dropout	0.3
	Bidirectional	LSTM with 100 neurons
	Dropout	0.3
	Convolutional 1D	100 filters of size 3, act_func ReLu
	Global Max pooling 1D	
	Fully connected	10 neurons, act_func ReLu
	Fully connected	1 neuron, act_func Sigmoid

Table 2: Classification performance on IMDb dataset,%.

Models	***Precision***	***Recall***	***F1-score***	***Accuracy***
LR (baseline)	86.62	85.54	86.08	85.90
CNN	90.04	90.31	**90.18**	**90.09**
CNN-LSTM	**90.90**	84.84	87.76	88.08
BiLSTM-CNN	83.08	**93.25**	87.87	87.03

Table 3: Classification performance on Sentiment 140 dataset, %.

Models	***Precision***	***Recall***	***F1-score***	***Accuracy***
LR (baseline)	71.61	74.63	73.09	74.23
CNN	76.17	79.47	77.78	77.24
CNN-LSTM	78.98	77.47	78.23	78.37
BiLSTM-CNN	**79.54**	**84.41**	**81.91**	**82.10**

7 DISCUSSION AND CONCLUDING REMARKS

Our research has shown that for sentiment analysis of social media texts, at least for binary classification, DNNs of relatively simple architecture with a small number of layers provide, in general, a level of accuracy acceptable enough for practical use.

For the selected English-language datasets IMDb and Sentiment 140, the classification accuracy using the Logistic regression model (Baseline) was 85.9% (74.23%), the CNN – 90.09% (77.24%), CNN-LSTM – 88.01% (78.36%), and BiLSTM-CNN – 87.03% (82.10%).

It should be noted that the accuracy of the classification can be increased if at the stage of pre-

processing to execute lemmatization (or stemming) which allow converting the words to their normal form. This is especially true for tweets that contain a large amount of user-generated vocabulary.

Also, it may be appropriate to use word embeddings weighted by their TF-IDF metric. It is also possible for out of vocabulary words try to use the weighted average value of the embeddings of the neighboring words with a certain window length, or replace the missing words with normalized TF-IDF embeddings transformed using the principal component method (SVD decomposition of the sparse TF-IDF matrix to reduce its dimensionality).

In our opinion, a promising direction for carrying out sentiment analysis of texts in social media is the use of models based on deep convolutional networks, or the synthesis of convolutional and recurrent networks, and applying the pre-trained embeddings (in particular, based on GloVe, Word2vec, FastText models).

At the same time, the use of pre-trained embeddings allows to start learning DNNs not from randomly generated values of model parameters, but already to some extent adapted to the task of text classification. Moreover, the learning process is accelerated and the generalization abilities of classifiers based on deep networks are improved.

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Analysis and Modeling of Globalization Processes in the Period of Crisis: The Impact of Military Actions in Ukraine on World Financial Markets

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Abstract: This research is applied. The article attempts to model and analyze the impact of the war in Ukraine on the world's globalization processes. This topic is relevant, but still little researched. Using the wavelet entropy method, models were built for the markets of natural gas, oil, gasoline, currency pairs EUR/USD, GBP/USD. Wavelet entropy is an indicator-precursor of crisis phenomena. The obtained results allow us to conclude that the war in Ukraine is a factor of crises in the studied markets and a factor that led to the reformatting of the world economic space.

1 INTRODUCTION

At the turn of the 20th-21th century, the problems and theoretical and methodological approaches of forecasting, analysis, and modeling of globalization processes under the influence of crisis phenomena of various etymologies are the objects of scientific research by scientists. The genesis of globalization theories from the Keynesian to the neoliberal model in the 20th century, which led to the construction and development of the post-industrial economy, testifies to its crisis in the modern world, as humanity faced such problems and manifestations of social life as political, social, economic instability (wars, the coronavirus crisis, the realization of the rights of nations to self-determination, the fight against hunger, the social stratification of the population by income level) and the challenges of human interaction with nature – ecological, energy, raw material, food, demographic crises.

All these challenges led to the conclusion that in the 21st century economic growth trends will remain, but they will acquire a new direction due to the fact that services and their role in the world economy will change qualitatively, and their rapid digitalization will take place, and the vector of scientific and technological progress will change.

To date, globalization processes are associated with such trends as the division of world markets into core and periphery, which leads to the emergence of conflicting interests between hegemon countries and "peripheral" countries; integration of national economies and peoples into a single system with the emergence of powerful regional associations; polarization of incomes in connection with the objective tendency to increase production volumes, growth of labor productivity; efficient and quick movement of capital and speculative activities of the financial elite; the emergence of contradictions between the virtual and real sectors of the economy; the need to unite in order to oppose international terrorism, world crises, etc.

Thus, according to the famous French economist, Nobel Prize laureate Maurice Alle, "the comprehensive globalization of trade between countries with significantly different wage levels (according to the exchange rate of currencies) cannot but ultimately lead everywhere – both in developed and less developed

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countries – only to unemployment, falling rates of economic growth, inequality, poverty. It is neither inevitable, nor necessary, nor desirable" (Vedernikova, 2017).

We can partially agree with this statement, since globalization processes, in addition to positive effects on the development of the world economy, in particular monetary and financial systems, also have negative ones, namely: a decrease in the degree of sovereignty and economic, political, energy independence of individual countries; the rapid spread of financial crises from one region to another, the significant impact of political, food, and energy crises on the economy of dependent countries (for example, since the beginning of the war in Ukraine and with the blockade of its seaports, the possibility of a food crisis in grain-importing countries has arisen), an increase forced migration, rising unemployment.

Today, the highest level of globalization is observed in the financial and investment sphere, when financial flows in the world economy are redistributed through financial markets, which are mostly not related to real markets for goods and services – all this periodically leads to the emergence of financial crises that practically destroy individual financial systems and markets, lead to socio-economic, demographic, financial instability. For example, the current regional financial crises in the USA, China and other major players, the global coronavirus crisis, the consequences of which are felt in all spheres of society to this day.

The financial crisis at the beginning of the 21st century was partially offset by the financial investments of various regions of the world in the US economy and the wars in Afghanistan and Iraq launched by NATO countries in response to the terrorist acts of September 11, 2001. These wars led to the active development of the military industry of the United States and, through inter-industry connections, had a positive effect on their economy.

Because of the war in Ukraine and in connection with the provision of military aid to it, the military-industrial complex of the United States and certain European countries are currently increasing their production volumes, therefore they need additional financial investments, which cannot but affect the state of global and regional financial markets. Therefore, the relevance of the proposed research topic is beyond doubt, and scientists and state managers need to have a toolkit that will allow them to follow the trends of the further development of the globalized financial system, and in particular, financial markets.

Therefore, the issues of analysis and modeling of globalization processes in crisis periods, which affect the state and development of financial markets, are becoming particularly relevant. Considerable attention is paid to the outlined scientific problem in the publications of both foreign and domestic scientists. Thus, the relationship between the bankruptcy rate of banking institutions and the deepest financial crisis in the emerging market of Turkey was investigated with sixteen different performance indicators using two alternative methods of stochastic analysis – frontier analysis (SFA) and data coverage analysis (DEA) (Isik and Uygur, 2021). The authors prove that efficiency indicators, as a rule, gradually deteriorate before a crisis, reach a "bottom" during a crisis and recover after a crisis.

Statistical analysis of financial relationships during the European sovereign debt crisis is used to model the movement of yields on the bond market (Campos-Martins and Amado, 2022). The resulting model allowed the authors to draw conclusions about the long-run and short-run contagion effects. Namely, it has been proven that in peripheral countries after the most acute phase of the sovereign crisis, there is a long-run contagion effect.

Many studies are devoted to the modeling of yield, volatility, the profitability of various financial instruments and the degree of their risk in financial markets using a wide range of methods. Thus, in the article (Labidi et al., 2018), the authors investigate the cross-quantile relationship between stock returns in developed and emerging markets with the study of time-varying characteristics using recursive sample estimates. The obtained results, based on the cross-quantile approach, show a heterogeneous quantile relationship of US, UK, German and Japanese stock returns to the returns of emerging market stocks. Systematic risk, according to the authors, as a rule, does not explain the dependence structure of regional and local markets, as it remains practically unchanged in the conditions of financial, geopolitical and economic uncertainties. Moreover, the cross-quantile correlation varies over time, especially in the low and high quantiles, indicating its tendency to jumps and breaks even in a stable dependence structure.

The multiplicative error model (MEM) is proposed for modeling the dynamics of illiquidity in financial markets (Xu et al., 2018). The authors empirically investigated the side effects of illiquidity and volatility in eight developed stock markets during and after the global financial crisis. It was found that the stock markets are interdependent both in terms of volatility and illiquidity, and in most of them, there is an increase in their side effects during the crisis. The authors conclude that illiquidity is a more important channel of shocks in stock markets compared to

volatility, and that the impact of illiquidity in US markets on other stock markets is significant.

GARCH models (ARMA-GARCH, ARMA-EGARCH and ARMA-FIGARCH) were used to study the impact of COVID-19 on the precious metals market (Bentes, 2022). The results of the study showed the presence of long memory in this market in the periods before and during the crisis. Conclusions were made regarding the significant impact of COVID-19 on the volatility of the precious metals market.

The high-dimensional conditional Value-at-Risk (CoVaR), which is based on the LASSO-VAR model, is used to study the systemic risks of financial contagion in crisis situations using the example of oil markets and G20 stock markets (Liu et al., 2022). The authors proved that in the event of a crisis in the oil markets, the stock markets of those countries that are connected with oil production will experience the greatest shocks.

Changes in the environment and depletion of natural resources have led to investment in renewable energy sources, and therefore to the need to analyze herd (collective) behavior in this market (Chang et al., 2020). In the article, the authors presented the results of testing the collective behavior of the renewable energy market using an empirical model during the periods of the global financial crisis and the coronavirus crisis. The authors proved the herd behavior of market participants during periods of crises in the oil markets. As a result, there is an invigoration of collective behavior in the stock markets as well. Attention is also paid to the study of contagion and the emergence of risks from fossil fuel energy markets to renewable energy stock markets.

One of the modern trends in monitoring, modeling and forecasting financial markets in crisis periods is the use of tools of nonlinear dynamics – fractal, recurrent, entropy, wavelet analyses, quantum modeling, etc. Thus, fractal and entropy analysis methods were used when modeling the cryptocurrency market in the conditions of the corona crisis (Danylchuk et al., 2020). The use of these methods made it possible to draw conclusions about cryptocurrency market trends and identify crisis situations. The wavelet entropy method, which was also used in the study, made it possible to conduct predictive analysis of the cryptocurrency market. The authors emphasized the universality of the methods for identifying crisis phenomena regardless of the nature of the crisis.

The article (Bielinskyi et al., 2021) is devoted to the identification of special conditions in the cryptocurrency market. The authors classified and adapted quantitative indicators to this market, analyzed their behavior in the conditions of critical events and well-known cryptocurrency market crashes.

Danylchuk et al. (Danylchuk et al., 2019) use entropy methods to determine the investment attractiveness of countries. For this purpose, regional stock markets are studied, as they are a reflection of the economies of countries.

Quantum modeling, namely the heterogeneous economic model, has been applied to stock markets (Kuzu et al., 2022). With the help of "measurement of the temperature of the series" crisis periods in the markets were detected. This model made it possible to adequately compare the features of the flow and consequences of various crises.

Modeling the impact of geopolitical risks on the state and dynamics of financial markets under conditions of crises of various natures is a little-researched field. This issue becomes especially relevant in the context of the creation of political and economic alliances and recent political crises. The article (Choi, 2022) presents the results of using the method of multiple and partial wavelet-coherent analysis regarding the influence of geopolitical problems on stock markets in the countries of Northeast Asia. Abdel-Latif and El-Gamal (Abdel-Latif and El-Gamal, 2020) investigate the global dynamic interrelationship between the prices of petroleum products, oil, financial liquidity, geopolitical risk and economic indicators of the economies of countries dependent on oil exports. For this purpose, the authors use the global vector autoregression (GVAR) model.

In the conditions of a full-fledged war in Ukraine, a special vector of scientific research is aimed at identifying the impact of the political and socio-economic crisis on the state and dynamics of world financial markets, which is reflected in a number of publications. Boungou and Yatié (Boungou and Yatié, 2022) provide empirical evidence of the negative impact of the war in Ukraine on the profitability of the global stock market. The largest decrease in the indicator was demonstrated by the markets of those countries geographically bordering Ukraine and Russia, as well as countries that condemned the war.

The impact of the war in Ukraine on financial markets is studied in the article (Lo et al., 2022) from the point of view of the dependence of the studied countries on Russian goods. The authors note that the war has increased instability in markets for all countries, but its degree is directly proportional to a country's dependence on Russian goods.

Boubaker et al. (Boubaker et al., 2022) came to the conclusion that more globalized markets were more affected by the war in Ukraine. However, the US market showed growing trends, Asian markets did

not react to this crisis.

So, modern crises of political, social, military and pandemic nature have led to a certain change in globalization trends in financial markets, which requires more detailed research and analysis from scientists. Classical methods of analysis and modeling do not always allow adequate assessment and forecasting of these processes, and therefore, there is a need to use a complex, interdisciplinary approach to solving this scientific task.

2 RESEARCH METHODS

In this study, the wavelet entropy method is used to model and analyze the impact of the war in Ukraine on globalization processes using the example of the gas, oil, petroleum products, and currency markets. The method of wavelet transformations is proposed for the analysis of periods in time series with the aim of detecting the evolution of parameters (Foster, 1996). Wavelet analysis based on wavelet entropy allows obtaining information about dynamic complexity (Sello, 2003).

We can describe wavelet entropy based on the work of Zunino et al. (Zunino et al., 2007). When studying the time series, which consists of sample values x_i, $i = 1,...,M$, when using a set of scales $1,...,N$, we will get a wavelet transformation (expansion)

$$X(t) = \sum_{j=1}^{N} \sum_{k} C_j \psi_{j,k}(t) = \sum_{j=1}^{N} r_j(t), \qquad (1)$$

$r_j(t)$ contains information about the series X in scale 2^{j-1} and 2^j.

Application of the theory of Fourier expansions allows us to determine the energy on each scale using

$$E_j = ||r_j||^2 = \sum_{k} |C_j(k)|^2. \qquad (2)$$

The total energy of the series can be calculated by

$$E_{tot} = ||X||^2 = \sum_{j=1}^{N} \sum_{k} |C_j(k)|^2 = \sum_{j=1}^{N} E_j. \qquad (3)$$

The next step is to determine the relative wavelet energy

$$p_j = \frac{E_j}{E_{tot}}, \qquad (4)$$

which provides hidden characteristics of the series in time and frequency spaces.

Using the concept of Shannon entropy, we can determine the normalized total wavelet entropy

$$E_{WT} = \frac{-\sum_{j=1}^{N} p_j \ln p_j}{X_{max}}. \qquad (5)$$

The improvement of the wavelet entropy calculation algorithm was the use of a window procedure (Quiroga et al., 1999). The following formula is used to calculate the wavelet energy for a time window

$$E_j^{(i)} = \sum_{k=(i-1)L+1}^{i\cdot L} |C_j(k)|^2, i = 1,...,N_T. \qquad (6)$$

The total energy in the window is calculated by

$$E_{tot}^{(i)} = \sum_{j=-N}^{-1} E_j^{(i)}. \qquad (7)$$

The change in time of relative wavelet energy and normalized total wavelet entropy is obtained by

$$p_j^{(i)} = \frac{E_j^{(i)}}{E_{tot}^{(i)}}, E_{WT}^{(i)} \sum_{j=-N}^{-1} p_j^{(i)} \cdot \frac{\ln p_j^{(i)}}{X_{max}}. \qquad (8)$$

3 RESULTS AND DISCUSSIONS

Oil is considered to be the benchmark of world economic activity. The price of crude oil reflects such market properties as stability/volatility and liquidity.

The article examines the oil, gas and gasoline market. The most popular grades of oil are Brent and West Texas Intermediate (WTI). For this purpose, daily values of Brent and WTI brand oil indices, natural gas and gasoline for the period from January 2015 to September 2022 were used. All calculations were performed in Matlab. Calculation parameters: window width 100 points, step – 10 points. Calculations were made according to the official website Yahoo Finance (Yahoo Finance, 2022).

In figures 1, 2 shows the dynamics of indices. Arrows indicate the periods of 2020 (the beginning of the coronavirus pandemic) and 2022 (the beginning of the war in Ukraine).

From figures 1, 2 we can note 2020 a drop in oil and gasoline indices. And in 2022, all indices experienced a rapid decline. The situation regarding 2020 is quite obvious and understandable. The announcement of the pandemic halted and slowed down economic activity. Demand for oil and gasoline fell.

The fall in 2022 is due to various factors, but in our opinion, the war in Ukraine should be considered the main one. Although the events unfold on the territory of Ukraine, the consequences are felt by almost all countries. European Union countries, Great Britain, the USA, Turkey, etc. support Ukraine not only with military aid, but also with the introduction of political and economic sanctions. Russia was a strong player in the oil and gas markets. The introduction of sanctions, the refusal of Russian gas forces the market and

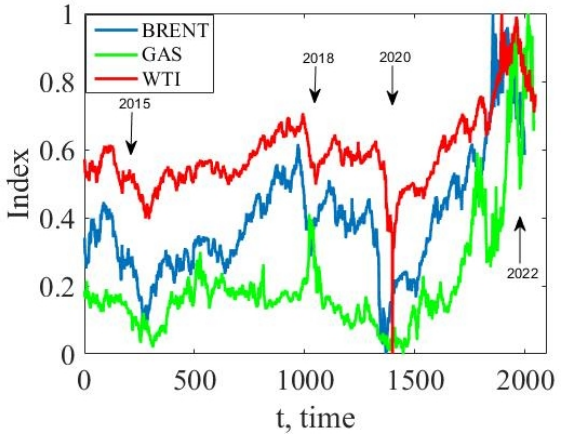

Figure 1: Comparative dynamics of oil (Brent and WTI) and gas indices.

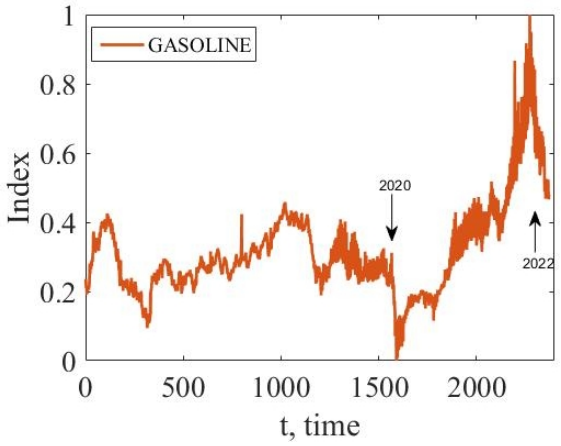

Figure 2: Dynamics of the gasoline index.

all market participants to quickly reorient themselves and reformat connections (e.g. increasing oil production in Norway, expected deliveries from Nigeria and Venezuela).

The use of wavelet entropy is due to the illustrative nature of this indicator and its predictive properties. The formation of three increasing entropy wavelet waves is a proven indicator-precursor of crisis phenomena of various natures (Soloviev et al., 2010). As soon as the third wave exceeded the maximum of the second wave, it can be argued that the market is waiting for a crisis ahead. The maximum of the third wave is a crisis itself. Therefore, the use of such an indicator allows for predicting a crisis and having time to take measures that can mitigate the consequences of the crisis. In addition, the wavelet transform provides a time-frequency representation of the signal, which allows you to obtain additional information that is not reflected in the time representation of the signal.

In figures 3–10 shows the results of wavelet entropy calculation for the gas, oil, and gasoline markets.

Analysis of the energy surface of the wavelet coefficients (figure 3) allows us to draw conclusions about the crisis situation in the gas market. On a small scale, there is a manifestation of disturbance. In wavelet analysis, small scales correspond to high frequencies.

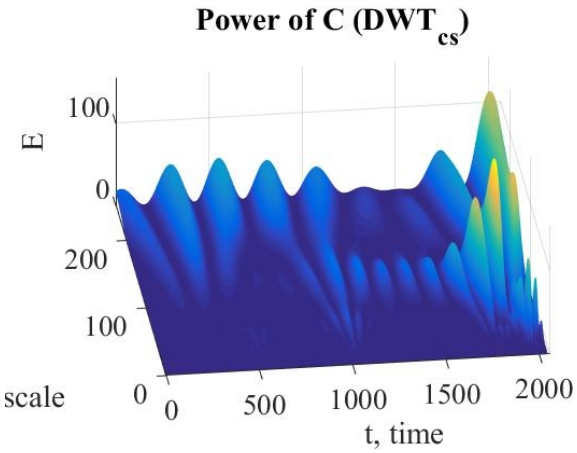

Figure 3: Wavelet coefficient energy for gas index.

Figure 4 shows the dynamics of wavelet entropy. We observe the formation of three waves in a neighborhood of 1750-2000 points, which is an indicator of the crisis. This crisis is the market's reaction to Russia's refusal to supply natural gas to Europe and the introduction of sanctions.

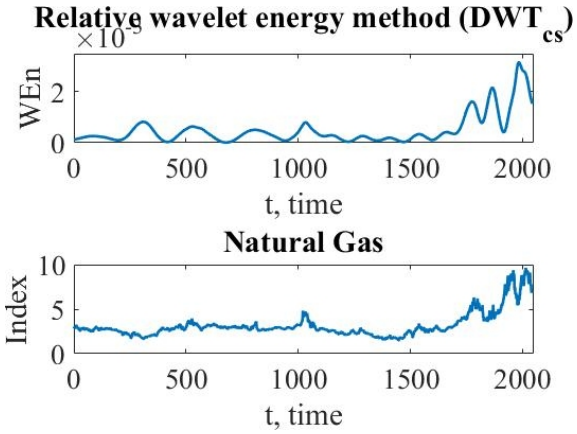

Figure 4: Wavelet entropy and dynamics of the gas index.

In figures 5, 6 shows the results of calculations for Brent oil, and figures 7, 8 – for WTI oil.

The energy of the wavelet coefficients shows a different situation for these two oil brands. This can be explained by the fact that Brent oil is traded on the markets of Europe and Asia, while WTI oil is traded on the US markets. But for the current time, the situation for these two brands of oil is similar. We see

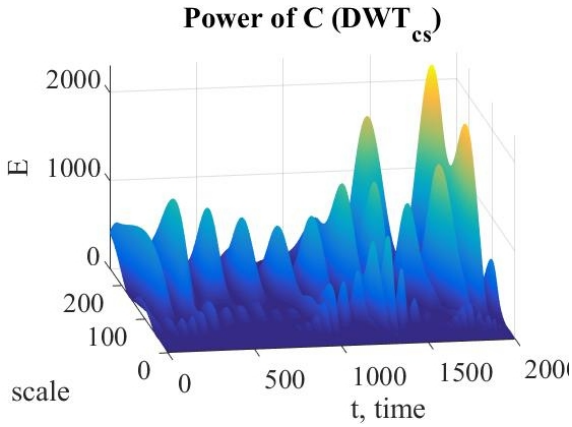

Figure 5: Wavelet coefficient energy for oil Brent index.

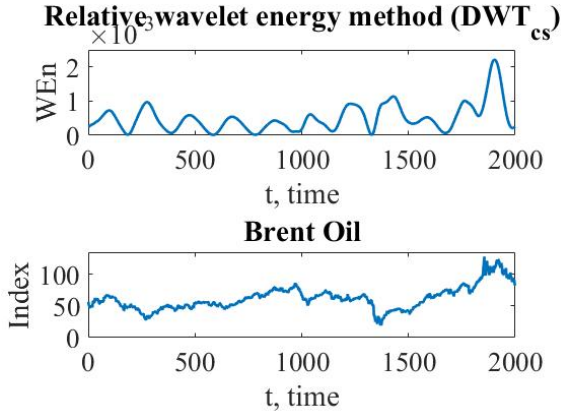

Figure 6: Wavelet entropy and dynamics of the oil Brent index.

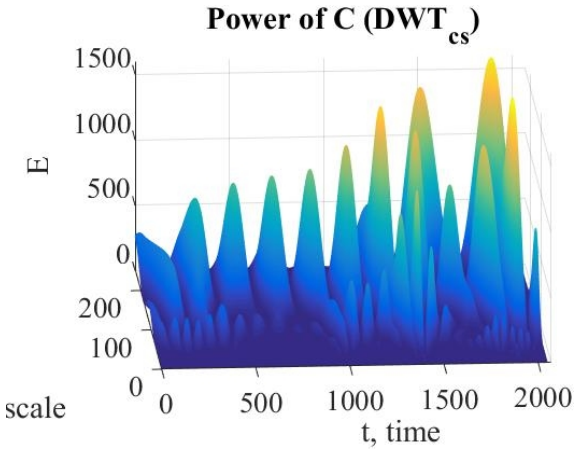

Figure 7: Wavelet coefficient energy for oil WTI index.

the formation of stable three waves, which indicates a crisis. What is happening in the oil market? It can be seen that the price of Brent and WTI oil benchmarks continue to fall. In our opinion, this is related to the war in Ukraine and the risk of recession. The

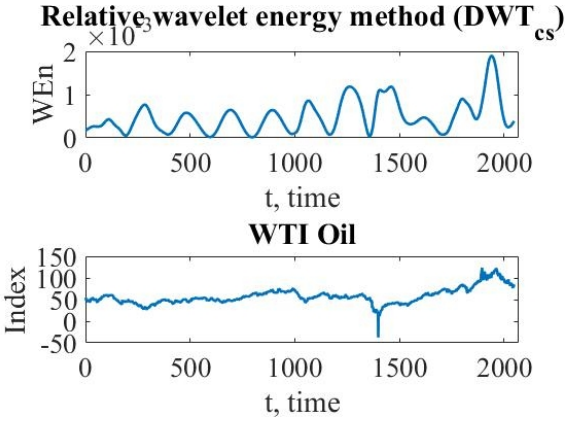

Figure 8: Wavelet entropy and dynamics of the oil WTI index.

European Union in the eighth package of anti-Russian sanctions "included a ceiling" on oil prices. In addition, the EU plans to ban sea imports of crude and refined oil from Russia. In response to the EU sanctions, Russia decided to reduce oil production by 3 million barrels per day, arguing that this is a lever to increase oil prices on the market. For Russia, the imposition of sanctions is a blow, as this is a budget-forming article (about 40% of budget revenues are in the form of taxes on hydrocarbon exports, and direct and indirect revenues related to this export make up to 60%). That is, the consequence of the introduction of sanctions will be a reduction in revenues from oil and gas. That is, it is precisely in this sector that Russia's "Achilles' heel" is, but the refusal of Saudi Arabia and other large Middle Eastern players to replace the Russian share of the oil market leads to fluctuations in its price, which in some way neutralizes the measures of the EU and the US countries regarding the oil embargo against Russia. They are trying to regulate the oil market. Thus, OPEC+'s decision is to reduce oil production by 2 million barrels per day, which should lead to an increase in oil prices. However, such a decision by OPEC+ has a reverse side. In particular, the United States began selling oil from reserves.

So, according to the results of the calculations, it can be stated that the oil and gas market is in a state of crisis, which was formed as a result of the war in Ukraine and the efforts of the main players to carry out its transformation, blocking Russia and reducing its influence on the world market. One such move by the global anti-Putin coalition (producing countries account for 60% of global GDP) is the declared creation of a buyers' cartel that has set a "price ceiling" for Russian oil and oil products. Even if India and China do not join the "price ceiling", the path of Russian oil to the world market will be difficult in December 2022, as the EU, Switzerland and Great

Britain will not only ban their factories and traders from buying it, but will also introduce sanctions on insurance, financing and ship freight, which will lead to the need for Russia not only to look for new sales markets, but also to build alternative supply chains to the world market from scratch.

In figures 9, 10 shows calculations for the gasoline market. Gasoline is a derivative of oil. Therefore, the behavior of the gasoline market should be similar to the behavior of the oil market. If oil becomes cheaper, then the price of gasoline should also fall.

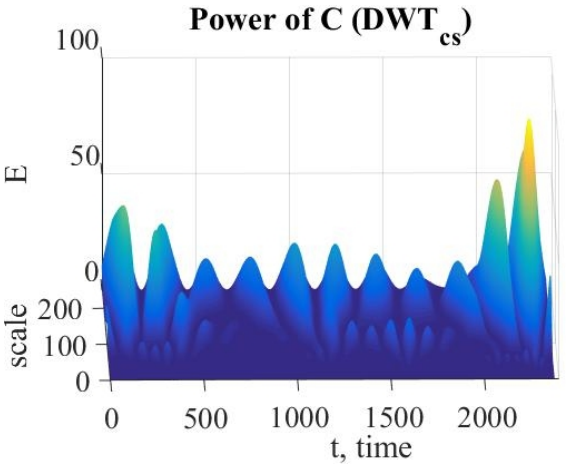

Figure 9: Wavelet coefficient energy for gasoline index.

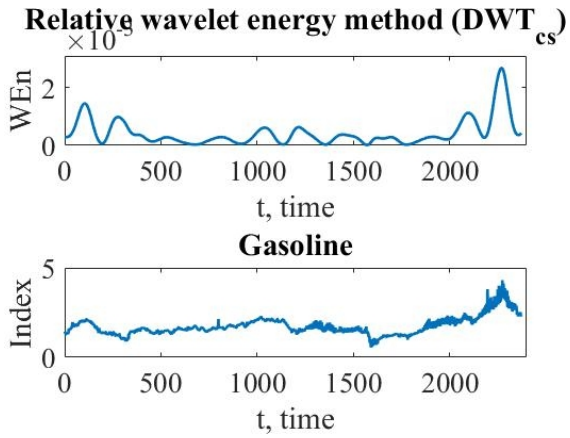

Figure 10: Wavelet entropy and dynamics of the gasoline index.

Comparing figure 9 from figure 5 and figure 7, we see that the energy surface for the gasoline market differs from the energy surfaces for oil. As you can see, the gasoline market is not stable. But starting from around the point of 1800, which corresponds to the year 2022 (figure 10), we observe the appearance of a triad of growing waves. And from this period, the behavior of the gasoline market becomes similar to the oil and gas market. And we state the crisis state of the market. What is the impact of the war in Ukraine? The world market of oil, oil products, and gas is being reformatted, and connections are changing. Ukrainian markets are also undergoing transformation, reorienting themselves towards the EU. It is obvious that the change of players in the market (both strong and not so) leads to instability, problematic issues of redistribution of resources.

The foreign exchange market is an important component of the financial market. Modeling and analysis of the currency market will allow an understanding of the economic and organizational relations between the participants.

In figure 11 shows the comparative dynamics of currency pairs EUR/USD and GBP/USD. These currency pairs are the most traded, which influenced the selection for the study.

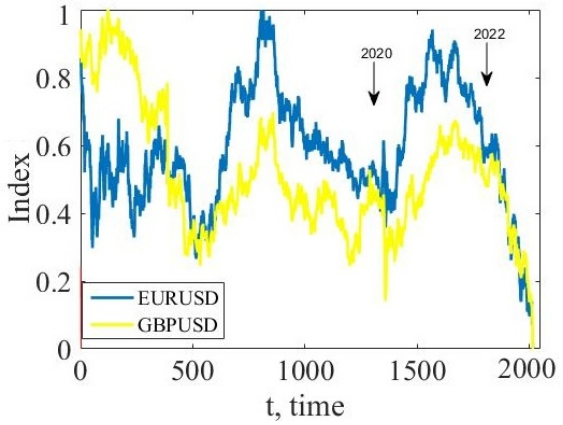

Figure 11: Comparative dynamics of indices of currency pairs EUR/USD and GBP/USD.

Figure 11 shows the sharp decline of currency pair indices in 2020. As for 2022, there is a drop in indices, but it is not of a rapid nature.

Applying the wavelet entropy method to the currency market allows you to get an answer to the question of the existence of a crisis in it. For both currency pairs, the formation of three waves, which is an indicator-precursor of the crisis phenomenon, was observed during 2015-2017 (within points 50-520, see figures 13, 15). The same situation is observed for the currency pair GBP/USD during the pandemic period (figure 15). The current situation for both currency pairs is marked by a gradual drop in the index values. The reasons for the subsidence may be the war in Ukraine, sanctions against Russia, the dependence of European states on Russian gas supplies, the political crisis in the EU regarding the support of sanctions and aid to Ukraine. The euro is the base currency, but it is also a tool for speculation.

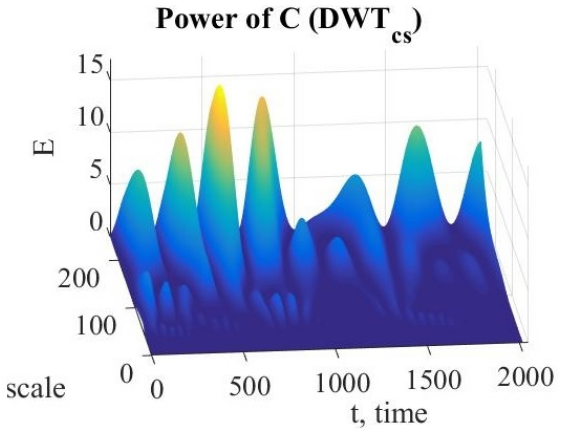

Figure 12: Wavelet coefficient energy for the currency pair EUR/USD.

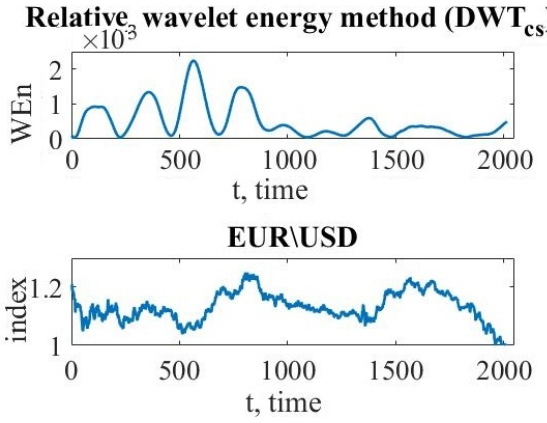

Figure 13: Wavelet entropy and dynamics of the currency pair EUR/USD.

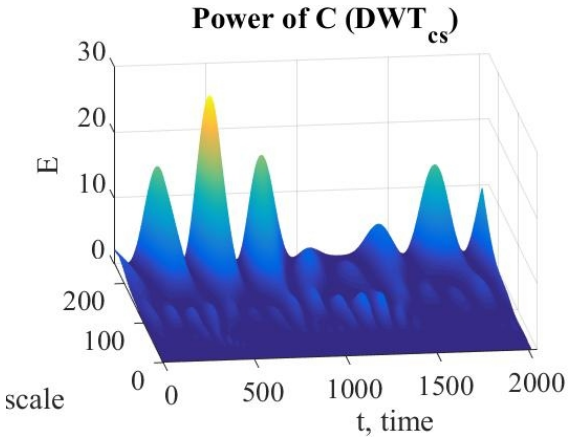

Figure 14: Wavelet coefficient energy for the currency pair GBP/USD.

Therefore, the simulation results indicate the absence of a crisis state at the time of the study. This market needs further monitoring, as the next wave is still in the process of formation.

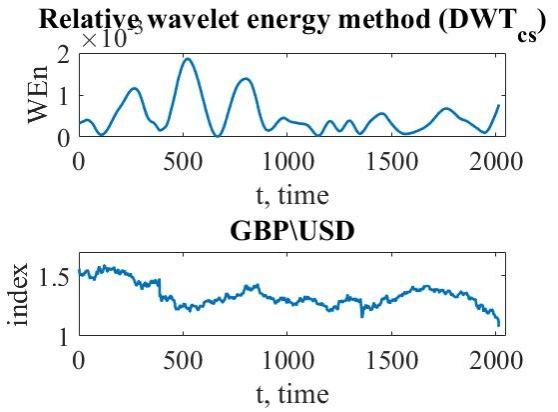

Figure 15: Wavelet entropy and dynamics of the currency pair GBP/USD.

4 CONCLUSION

So, based on the results of modeling and analysis of oil, gas, oil products and foreign exchange markets using the wavelet entropy method, we can conclude that the war in Ukraine can be considered an influential factor in the crisis phenomena that are already present or are forming in these markets. Wavelet entropy models demonstrated the existence of a crisis in the oil, gas and gasoline market. In the currency market, the main currency pairs show a gradual, but rather long-term, decline. The currency market has its own characteristics and requires constant monitoring. Using the wavelet entropy method to model this market will allow early identification of a crisis state. The obtained results do not contradict the conclusions that the oil market has a heterogeneous effect on all financial assets, the peak of its influence falls precisely during the war in Ukraine (Adekoya et al., 2022), and globalized markets are more affected by the war in Ukraine (Boubaker et al., 2022) and others. Globalization processes in the world economic space carry with them, in addition to advantages, certain threats. Today, these threats exist in the market of oil, gas and other energy carriers. The war in Ukraine, unleashed by Russia for its own self-assertion, a huge desire for world domination and an overwhelming fear of losing what it has, forced the international community to review the structure, connections and processes of globalization in world economic activity.

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Nonlinear Analysis of the Dynamics of Sales of Electric Automobiles in the Chinese Market

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Abstract: The article is devoted to the research of the dynamics of sales of electric automobiles in the Chinese market using non-linear analysis tools. The relevance of the work is due, on the one hand, to the sharp development of the electric vehicle segment in the global automobile market, in which China's market share was 45% of sales in 2020. On the other hand, the use of different approaches to forecasting the sales of electric vehicles leads to unsatisfactory results. The article analyzes the nature of the properties of the dynamics of sales of electric automobiles in the Chinese market using non-linear analysis tools. The initial data for the analysis is the time series of monthly sales volumes from January 2016 to June 2022 of the leading manufacturers of electric vehicles. For the research, three methods of nonlinear dynamics were used: the Hurst normalized range method, phase analysis, and the recurrence plots method. The calculations were carried out in the R software environment. As a result of applying the Hurst normalized range method, the fractal nature of time series, the property of trend stability, and the presence of long-term memory were revealed. The use of phase analysis made it possible to reveal cyclicity in dynamics, to evaluate the characteristics of attractors (quasi-cycles) and their features for each agent on the market. The construction of recurrence plots, their topological and quantitative analysis confirmed the deterministic nature of the dynamics. The results of the research can be used to select relevant forecasting methods and their parameters.

1 INTRODUCTION

The policy of developed countries regarding the transformation of the fuel and energy market indicates that transport (one of the main consumers of energy) has begun to move rapidly towards reducing the consumption of fossil fuels. The most important indicator of change in this process has been an increase in the production of electric vehicles, which is increasing amid high expectations of pent-up demand.

The main reasons that favor the increasing popularity of electric vehicles in the world can be divided into three groups. The first group includes legislative factors: sales are stimulated in different countries by various methods. The most popular of them: subsidies or discounts when buying the automobile free parking spaces (as opposed to paid spaces for cars with internal combustion engines), free charging of cars in specially designated places. The second group of factors is concern for the environment: governments encourage citizens to buy automobiles that do not produce carbon dioxide during operation, and socially responsible citizens tend to buy such automobiles. The third group of factors includes energy security: the price of oil and gasoline depends on the global market. The number of countries that produce and export them is small; a large number of countries may suffer as a result of unpredictable phenomena in the oil market or supply disruptions. In contrast, electricity generation is more diversified in terms of its generation capacity.

Competition in the field of electric transport gives rise to new technologies, enterprises, business models, and, finally, new markets. Today, at the stage of formation of the global market for electric vehicles, the total volume of investments in the production of electric vehicles and the creation of an infrastructure for it is rapidly increasing all over the world. The sequence of decisions that will be made during this period is laid the foundation for the future architecture

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of the global market: from educational and production standards, the organization of urban infrastructure to new business models and market regulation conditions.

The automotive market is an object that is developing quite actively, and the importance of the transport business for the global economy and the economies of individual countries is constantly growing. According to Bloomberg rating agency estimates by 2040 (in less than 20 years) electric automobile sales will account for 2/3 of the global automotive market (McKerracher and Wagner, 2021). Therefore, the study of the nature of the dynamics of the electric vehicle market is of significant scientific and practical interest.

The global market for electric vehicles is developing, so it is necessary to determine the models for its development. Based on the statistical analysis of the electric vehicle market, it can be revealed that China is today the main player in electric vehicle sales and market penetration. In particular, in 2013, China achieved phenomenal growth in vehicle sales specifically in the segment of battery electric vehicles (BEV) and hybrid vehicles (PHEV). For six consecutive years from 2012 to 2017, the annual growth rate of the market volume is at least 45 per cent (Jin and He, 2019). And in 2020, according to the International Energy Agency (Paoli et al., 2022), the Chinese market accounted for almost 45 per cent of global sales. Thus, the study of the development dynamics of the electric vehicle market in China is necessary as a basis for further research in the markets of other countries.

2 RELATED WORKS

Zhang et al. (Zhang et al., 2017) presents Singular Spectral Analysis (SSA) as a one-dimensional time series model and Vector Autoregressive Model (VAR) as a multivariate model that displays the sales volume of automobiles with electric and hybrid engines in China. Empirical calculation results show that SSA satisfactorily indicates the market trend. The VAR model, which contains exogenous parameters related to the market, according to the authors, can significantly improve the accuracy of the results when used to build forecasts.

The price of charging the automobile is important for owners during its operation. Zhang et al. (Zhang et al., 2018) proposes a pricing model for public-private partnership projects of automobile charging infrastructure in China, which is based on the use of the system dynamics (SD) method. In paper (Dhakal and Min, 2021), based on predictive data on the number of automobiles, a simulation of the spread of electric vehicles is presented using the example of France and Germany.

Articles (Zhu and Du, 2018; Ensslen et al., 2019) are devoted to predicting the dynamics of the distribution of electric vehicles within the European Union. For this, logistic models are used, in particular, the logistic and Bass diffusion model (Zhu and Du, 2018), which is used in (Ensslen et al., 2019) to predict the number of cars used in Beijing.

An overview of the methods that are used to predict the penetration of electric vehicles into the passenger vehicle market is presented in (Jochem et al., 2018). Two groups of models are distinguished: econometric models with disaggregated data (such as discrete choice) and simulation models based on agents. Some methods have been found to have a stronger methodological basis, while others require complex datasets or can be more flexibly combined with other methods. Despite the absence of a dominant method, Jochem et al. (Jochem et al., 2018) justify the advantage of hybrid approaches and managed data that take into account micro and macro aspects, which allows obtaining more accurate results.

In (Rietmann et al., 2020), using a logistic growth model, a long-term forecast of stocks of electric vehicles in 26 countries on five continents is provided. The findings show that in 2032, 30 per cent of the global vehicle fleet will be electric vehicles. However, the results obtained by the authors also demonstrate significant differences between countries, which may be due to differences in government support.

Electric vehicle sales are influenced by many factors (especially in China) and there are not many sales forecasting models available. In particular, Wan et al. (Wan et al., 2021) used decomposition and integration procedures based on the TEI@I methodology. So, in the forecasting model, principal component regression analysis (PCR) was used to work with a linear relationship. Then a BP neural network and a support vector machine (SVM) were used to work with non-linear dependence. In the last step, all models were integrated together. The Granger causality test and the degree of gray correlation are used to quantify the factors that affect EV sales through consumer network data analysis. On the example of two automobile models, it was found that the PCR-BP models and the PCR-SVM models have better predictive performance than one model. According to the authors, this approach is more suitable for making decisions about forecasting markets for similar products.

Dingab and Li (Dingab and Li, 2021) proposes to use the modified gray model as a promising tool for

predicting sales of electric vehicles.

The use of different approaches to forecasting the sales of electric vehicles indicates that the quality of the results is not satisfactory. A common feature of almost all almost all forecasting methods that are presented in the review is that they provide for the subordination of volume dynamics to a linear paradigm. However, today it is a recognized fact that the dynamics of most markets does not obey the law of normal distribution, and therefore their modeling by traditional methods leads to significantly unsatisfactory results. The linear paradigm has been replaced by a nonlinear paradigm (Peters, 1994), which is based on the recognition of the fractal nature of the market and is actively developed for analysis and modeling, including in (Perepelitsa and Maksyshko, 2012) and (Maksyshko et al., 2020). This statement is based on such features of time series (TS) of indicators characterizing financial markets: the lack of independence of levels, the presence of long-term memory, and others (Derbentsev et al., 2019; Kmytiuk and Majore, 2021). The use of statistical methods for their research and further forecasting (as the ultimate goal of the analysis) turns out to be inadequate. Therefore, there is a need to use new, different from statistical, methods of analysis.

The purpose of this research is to diagnose the nature and properties of the dynamics of sales of electric vehicles in the Chinese market using non-linear analysis tools for further use in choosing a relevant forecasting method.

3 MATERIALS

The object of analysis of this research is the sales volumes of cars, which are contained in the reports of the China Association of Automobile Manufacturers (CAAM, 2022) and published by the online publication "Chinese Cars" (Chi, 2022).

An analysis of the structure of the electric vehicle market in China revealed that in the period from January 2016 to June 2022, 37.5 per cent of the electric vehicle market belongs to five automakers, namely: BYD, Mercedes-Benz, Roewe, Geely, Chery. Most of these companies are representatives of the Chinese automotive industry, which is due, in particular, to state support for manufacturers of this type of transport (Qian et al., 2019). Let's characterize these companies in more detail.

BYD is the only automobile manufacturer that has mastered batteries, electric motors, and vehicle control technologies. BYD was founded in 1995 as a pioneer in the battery technology industry. Its stated goal is to change the world by creating a complete zero-emission ecosystem that runs on clean energy and reduces dependence on oil. BYD's innovative products are leaders in many sectors, including battery electric vehicles, buses, medium and heavy duty trucks and forklifts. In 2003, the company entered the automotive business, and in 2005, the first BYD brand automobile went on sale (BYD North America, 2022). The company holds 16 per cent of the electric vehicle market in China.

Mercedes-Benz is a world-famous automaker that in recent years has been investing more resources in its advanced research and design capabilities in China as the new center of gravity for the auto industry (Shirouzu, 2021). The company holds 9 per cent of the electric vehicle market in China.

Roewe is owned by the Shanghai Automotive Industry Corporation (SAIC) and is one of the few Chinese luxury brands that actually manufacture modernized copies of older Rover models (Roewe, 2022). The company holds 6 per cent of the electric vehicle market in China.

Geely Auto Group is a leading automobile manufacturer that was founded in 1997 as a subsidiary of Zhejiang Geely Holding Group. For the past five years, the company has maintained its position as the best-selling Chinese brand (Geely, 2022). The company holds 4 per cent of the electric vehicle market in China.

Chery was founded in 1997 under the patronage of state-owned companies and holdings, as well as smaller investors. In 2006, Ukraine was one of the first countries to introduce the assembly of automobiles of this brand outside China. In 2012, in pursuit of a globalization strategy, Chery and Jaguar Land Rover Motors jointly invested in the establishment of Chery Jaguar Land Rover Motors Co., Ltd., which is China's first Sino-British automobile joint venture (Chery, 2022). The company holds 3 per cent of the electric vehicle market in China.

Thus, we will analyze the nature of the dynamics of the behavior of agents of the electric car market in China on the basis of time series (TS) of monthly sales volumes of automobile companies (manufacturers) BYD, Chery, Geely, Mercedes-Benz and Roewe. These automakers were selected based on the fact that they are among the top 9 most popular electric mobile brands in terms of sales for the period from January 2016 to June 2022 (Chi, 2022) and have sufficient data for analysis for this period. When analyzing the dynamics, we will identify the sales volumes of electric vehicles with the volume of demand for them.

4 METHODOLOGY

To identify the nonlinear (chaotic) behavior of economic data, various methods of time series analysis are used (Faggini, 2014). In particular, tests for deterministic chaos have been developed for this purpose, which allow one to study the main features of chaotic phenomena: nonlinearity, a fractal attractor, and sensitivity to initial conditions.

In this research, to diagnose the nature and properties of the dynamics of sales of electric vehicles in the Chinese market, we will use three tools for analyzing nonlinear dynamics, namely: traditional R/S-analysis – the Hurst normalized range method, phase analysis and recurrence analysis.

For the purpose of a general assessment of the fractal properties of time series, we use the Hurst normalized range algorithm for analysis (Peters, 1994). It is known that if the system gives the Hurst statistics for a sufficiently long period, then this indicates the result of interrelated events. As is known, a measure of the mutual connection of events is the correlation coefficient. The influence of the present on the future can be represented by the following correlation:

$$C = 2^{2H-1} - 1, \tag{1}$$

where C – measure of correlation,

H – Hurst exponent.

The range of the Hurst exponent (H) is the interval [0; 1]. The indicator value allows classifying all time series into three groups:

1) $H = 0{,}5$;
2) $0 \leq H < 0{,}5$;
3) $0{,}5 < H \leq 1$.

The value $H = 0{,}5$ indicates a random time series: the events are random and not correlated ($C = 0$ according to (1)). The present does not affect the future.

If $H \in (0{,}5; 1]$, then the considered time series is persistent or trend-resistant and is characterized by the effect of long-term memory. Events are the more correlated, the closer the value is to 1 (correspondingly, C also approaches 1 or 100 per cent correlation according to (1)).

The value $H \in [0; 0{,}5)$ corresponds to antipersistent or ergodic time series. In a loose definition, antipersistence means reverting to the mean or, in other terminology, reversing (alternating positive and negative increments) more often than in a random process. Thus, the Hurst exponent (H) is decisive in diagnosing the nature of the development of a system or process.

To check the validity of the results on the presence of long-term memory based on the value of the Hurst exponent (H), we will use a test for random mixing of the levels of the time series.

Phase analysis is one of the effective methods for obtaining information about the nature of the dynamics of the system under consideration (Perepelitsa and Maksyshko, 2012). To the time series ($X = (x(t), t = \overline{1,n})$) that characterizes the dynamics of demand in the market of electric vehicles, we will apply such a presentation method, which can be used to return from the observed state of the system to its previous state. This "return" is implemented by the method of time delays and is produced by constructing a phase trajectory (phase portrait) of dimension ρ:

$$\Phi_\rho(X) = \left\{(x(t), x(t+1), ..., x(t+\rho-1)), t = \overline{1,n}\right\}, \tag{2}$$

which is a set of points called "ρ-history". For any time series, the list of all its M-histories determines the corresponding set of points in the pseudo-phase (or lag) space. In this case, when using the terms "phase portrait" or "phase trajectory" it means that the neighboring points of the set (2) are connected by segments of a straight or curved line for clarity.

Thus, the graphic representation of the system on the phase plane (or in the phase space), along the coordinate axes of which the values of the variables of the system (TS levels) are plotted, is called the phase portrait of the system. The behavior of phase points in time, which is described by the phase trajectory and the set of such phase trajectories for any initial conditions form a phase portrait. A phase portrait is a mathematical method for representing the behavior of a system and a geometric representation of individual movements, and also displays the state of equilibrium, periodic and chaotic movement of a phase point, the logic of the system's behavior and its dependence on external and internal influences.

Objective information about the nature of the behavior of a dynamic process can be obtained by observing the time series X, based on the Takens theorem (Takens, 1981): if the system generating the time series is m-dimensional and inequality $\rho \geq 2m + 1$ is satisfied, then in the general case, phase trajectories reflect the dynamics of the system under study. There is a dipheomorphism between the phase trajectories and the true data generated by the system. This result allows one to draw conclusions about the behavior of the system based on observational data, and, moreover, to obtain information to predict this behavior.

Analysis of the phase portrait makes it possible to determine the type and characteristic features of the dynamics of a particular system. To deepen such an analysis, Eckmann et al. (Eckmann et al., 1987) proposed in 1987 a new diagnostic tool, the recurrence plot.

The recurrence plot is a projection of the ρ-dimensional pseudo-phase space onto the surface. Let point x_i-correspond to the point of the phase trajectory (2), which describes a dynamical system in m-dimensional space at times $t = i$, for $i = 1, ..., n$. Then the recurrence plot is an array of points, where non-zero elements with coordinates (i, j) correspond to the case when the distance between x_i and x_j is less then γ:

$$RP_{i,j} = \theta\left(\gamma - \left\|x_i - x_j\right\|\right), \quad x_i,\ x_j \in R^m,\ i, j = 1, ..., n, \tag{3}$$

where γ – size of the point x_i,

$\left\|x_i - x_j\right\|$ – distance between points,

$\theta(\cdot)$ – Heaviside function.

For the practical reconstruction of the attractor for a given time series, it is necessary to determine the values of the parameters: ρ – the embedding dimension of the time series, d – the time lag of the time series (Rotshtein and Katelnikov, 2014).

To determine the time lag of the time series, the function (S) – the adjusted mutual information function (AMI) was used for the time series under research, which takes into account non-linear correlations (Hegger and Kantz, 1999):

$$S = -\sum_{ij} p_{ij}(\Phi_\rho(X)) \cdot \ln \frac{p_{ij}(\Phi_\rho(X))}{p_i p_j}, \tag{4}$$

where $p_{ij}(\Phi_\rho(X))$ – joint probability that an observation falls into the i-th interval and the observation time d later falls into the j-th;

p_i – the probability to find a time series value in the i-th interval;

p_j – the probability to find a time series value in the j-th interval.

To calculate the optimal time lag of the time series (d), we will use the tseriesChaos library of the R environment.

To determine the embedding dimension of the time series, the false nearest neighbor method given in (Kennel et al., 1992) was used. This method is based on the assumption that at the next iterations the neighboring points of the phase trajectory remain sufficiently close. But if the nearest points move away from one another, then they are called false nearest neighbors. The task of the method is to choose such a dimension of the time series (ρ), in which the proportion of points that have false neighbors is minimized.

Based on the calculated parameters of the embedding dimension and time lag, recurrence diagrams of time series are built. The analysis of the statistical characteristics of the recurrence diagram makes it possible to determine the measures of complexity of the structure of the recurrence diagrams (Wallot, 2017):

- percent recurrence (%REC),
- percent determinism (%DET),
- average (ADL) and maximum (MDL) diagonal lines lengths of the recurrence diagram.

The construction and determination of the statistical characteristics of recurrence diagrams will be implemented in the R environment using the tseriesChaos and nonlinearTseries libraries.

Based on the analysis of the statistical characteristics of the recurrence diagram, it is possible to determine the presence of homogeneous processes with independent random values; processes with slowly changing parameters; periodic and oscillating processes that correspond to nonlinear systems. Thus, the analysis of the recurrence surface makes it possible to evaluate the characteristics of a non-linear object on relatively short time series, which makes it possible to make prompt decisions regarding the control of the object.

5 RESULTS

The analysis of the behavior of Chinese electric automobiles market agents was carried out on the basis of monthly sales data from January 2016 to June 2022 of five automobile companies (BYD, Chery, Geely, Mercedes-Benz, Roewe) (figure 1).

Time series of sales of electric vehicles in the Chinese market denoted by $X_k = (x(t),\ t = \overline{1,n}),\ k = \overline{1,5}$ where n is the length of the time series, k is the index assigned to the corresponding manufacturer (in order of priority): BYD, Chery, Geely, Mercedes-Benz, Roewe.

Table 1 shows the results of the Hurst exponent calculations (H) for these time series and the value of the Hurst exponent (H_{mixing}) obtained after applying the mixing test.

Table 1: The value of the Hurst exponent for the series of dynamics of sales volumes of electric automobiles of manufacturing companies for the period from January 2016 to June 2022.

Manufacturer (TS)	H	H_{mixing}
BYD (X_1)	0,84655	0,56659
Chery (X_2)	0,82696	0,58156
Geely (X_3)	0,81668	0,57214
Mercedes-Benz (X_4)	0,86762	0,54563
Roewe (X_5)	0,87330	0,59666

According to table 1, we can conclude that all time series of sales volumes (demand for electric automobiles) of all manufacturers have signs of persistence,

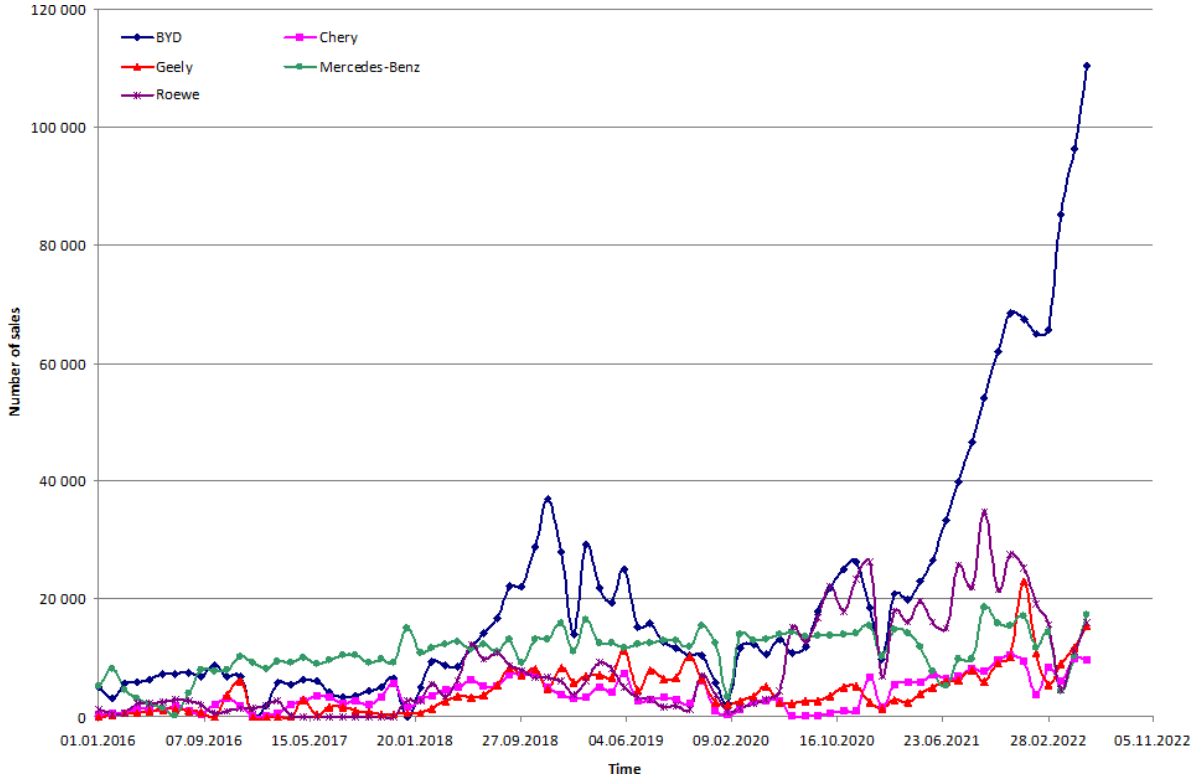

Figure 1: Number of sales of electric vehicles in the Chinese market from January 2016 to June 2022.

that is, they have a long-term memory. This is evidenced by the following:

a) the value of the Hurst exponents for all time series are in the interval $H \in [0,817; 0,873]$, which corresponds to the area of black noise;

b) the results of the mixing test ($H_{mixing} \in [0,546; 0,597]$) confirm the significance of the time series structure: its violations lead to the complete destruction of the trace of long-term memory.

The presence of significant Hurst statistics for the time series of sales of electric vehicles is explained by the following reasoning.

The change in the volume of demand for electric vehicles is based on an increase in the overall demand for vehicles, the perception of buyers of a certain expediency to follow the trend in energy security (increased charging stations), legislative incentives and social responsibility (concern for the environment). The demand for electric vehicles is partly determined by fundamental information such as the state of the energy market, public discussion of environmental issues, current economic circumstances, expectations, and so on. This information is often useful in making decisions when purchasing a type of vehicle. Of great importance in this belongs to the marketing activities of manufacturing companies, the volume and quality of their offers on the market. Another important component of demand volumes is the extent to which buyers are able to pay for a new and usually more expensive product (an electric car). This "sensory component" is also analyzed, and as a result, a certain range of demand volume is formed around the existing one. This combination of information and thoughts results in displacement of volumes. If buyers see that the trend is in line with their positive expectations for a particular electric vehicle, they start buying like others. Yesterday's activity has an impact on today – the market remains mindful of yesterday's trend. The bias will change when demand reaches the upper limit of some actual value. At this point, the offset will change. The interesting thing is that the "range" of demand does not remain constant, but changes. New information regarding a particular electric vehicle (innovations and shortcomings) or the market as a whole can change this range and cause a sharp increase in sales volumes of the manufacturer (in particular, the introduction of breakthrough innovations) or a negative turn in the market situation, or for an individual seller (in particular, in case of deficiencies, and so on).

Let's proceed to the consideration of the results of the phase analysis of time series $X_k, k = \overline{1,5}$ of

sales of electric vehicles in the Chinese market. Figure 2 shows phase portraits in a two-dimensional pseudo-phase (lag) space $\Phi_2(X_k) = \{(x(t), x(t+1))\}$, $k = \overline{1,5}$.

A more detailed analysis of phase portraits makes it possible to identify the following individual features.

In the dynamics of sales of the automobile company BYD (Figure 2a)), at the beginning of the observation period for the first 5 years (from January 2016 to February 2021), almost stable quasi-cycles of length 7 were observed, which indicates the presence of long-term memory in them (confirmed by the value $H \approx 0{,}85$). However, since February 2021, the dynamics has changed dramatically in the direction of increasing sales volumes and almost no cyclicity when moving along the bisector of the coordinate angle. This indicates an increase in the memory depth of the time series.

The dynamics of sales of automobile companies Chery and Gelly (Figure 2b), c)) are characterized by shorter quasi-cycles (length 4 or 5), and there is an increase in the amplitude of these quasi-cycles in the final interval of the time series (from February 2021 to June 2022), but no significant movement along the bisector of the coordinate angle is observed. The dynamics is characterized by less trend resistance, which is confirmed by the values $H \approx 0{,}83$) and $H \approx 0{,}82$) for the respective manufacturers.

The dynamics of sales of automobile companies Mercedes-Benz and Roewe (Figure 2d), e)) is characterized by the presence of the longest quasi-cycles (length 9), their slow movement along the bisector of the coordinate angle (increase in volumes) and an increase in amplitude. This is evidence that the dynamics of sales volumes of these manufacturers is characterized by the greatest trend resistance (confirmed by the value of the Hurst exponent $H \approx 0{,}87$) for both companies).

Thus, the analysis of phase portraits $\Phi_2(X_k)$ in a two-dimensional pseudo-phase (lag) space makes it possible to identify the characteristic features of the dynamics of sales volumes of each agent in the Chinese electric car market.

At the first stage, using the tseriesChaos library of the R environment, the values of the embedding dimension (ρ) and the time lag (d) of the considered time series were calculated (table 2).

At the second stage, using the tseriesChaos and nonlinearTseries libraries in the R environment, recurrence plots were constructed (figure 3a)-f)) and their statistical characteristics were determined (table 3).

The topology of the recurrence plots for electric automobiles sales in China shows abrupt changes in the dynamics of the system that generates the time series and causes white areas or bands to appear. On the recurrence plots, there is a gradual change in the parameters of the behavior of the agents of the automobile market, and there is also a drift of the attractor (white lower and upper corners of the diagram, crosses). The absence of short diagonal stripes on the recurrence plots indicates the absence of a stochastic process and the non-return of the trajectory to the same region of the phase space in different time periods.

Table 2: The value of the embedding dimension (ρ) and time lag (d) for the series of dynamics of sales volumes of electric automobiles of manufacturing companies for the period from January 2016 to June 2022.

Manufacturer (TS)	The embedding dimension (ρ)	The time lag (d)
BYD (X_1)	5	9
Chery (X_2)	4	3
Geely (X_3)	4	3
Mercedes-Benz (X_4)	4	1
Roewe (X_5)	6	2

Table 3: Statistical characteristics of recurrence plots of electric automobiles sales in China from January 2016 to June 2022.

Manufacturer (TS)	%REC	%DET	ADL	MDL
BYD (X_1)	2,381	100	0	42
Chery (X_2)	1,429	100	0	70
Geely (X_3)	1,429	100	0	70
Mercedes-Benz (X_4)	1,333	100	0	75
Roewe (X_5)	1,471	100	0	68

The determinism of the behavior of companies in the automobile market is confirmed by the calculated statistical characteristics of recurrence plots, which are shown in table 3.

The value of the %REC indicator for all time series falls within the interval from 1% to 5%, which indicates the regular behavior of the time series.

The measure of determinism (%DET) of the recurrence plot characterizes the level of system predictability. Diagonal structures show the time during which a segment of the trajectory comes very close to another segment of the trajectory. For all five recurrence plots, the level of predictability is 100%. Note that this measure does not determine the real determinism of the process.

The average diagonal lines lengths (ADL) characterizes the average time during which two sections of the trajectory pass close to each other, and can be considered as the average predictability time of the system. An interesting fact is that, according to the

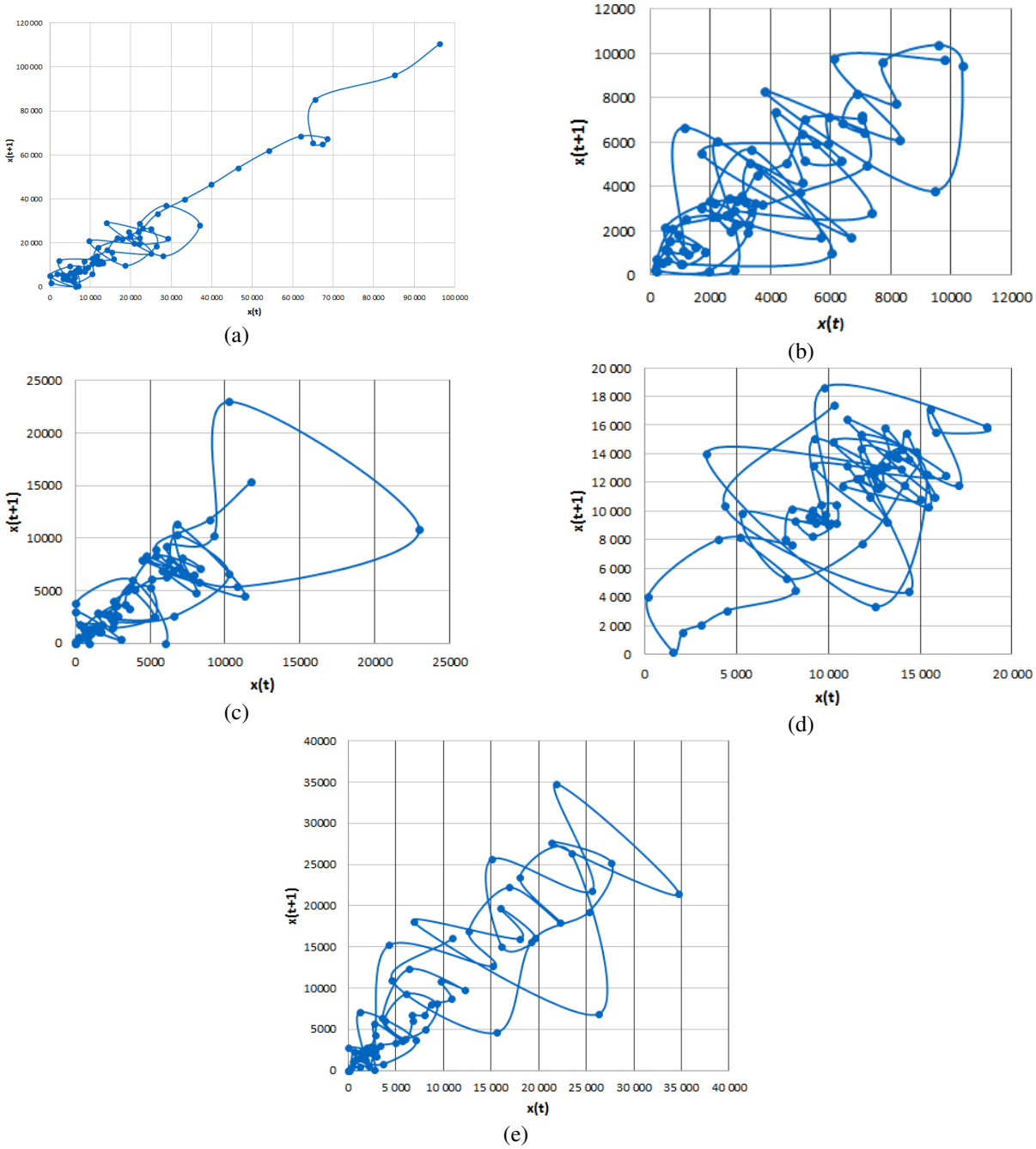

Figure 2: Phase portraits in a two-dimensional pseudo-phase space $\Phi_2(X_k) = \{(x(t), x(t+1))\}, k = \overline{1,5}$ for time series $X_k, k = \overline{1,5}$ from January 2016 to June 2022: a) BYD, b) Chery, c) Gelly, d) Mercedes-Benz, e) Roewe.

calculation results, the smallest average predictability time of time series is 0.

The maximum diagonal lines lengths (MDL) characterizes the length of the trend. The shortest trend is in the BYD time series (42 points), and the longest is in Mercedes-Benz (75 points).

6 CONCLUSION

The research analyzes the nature and properties of the dynamics of sales of electric automobiles in the Chinese market using non-linear analysis tools.

The initial data for the analysis is the time series

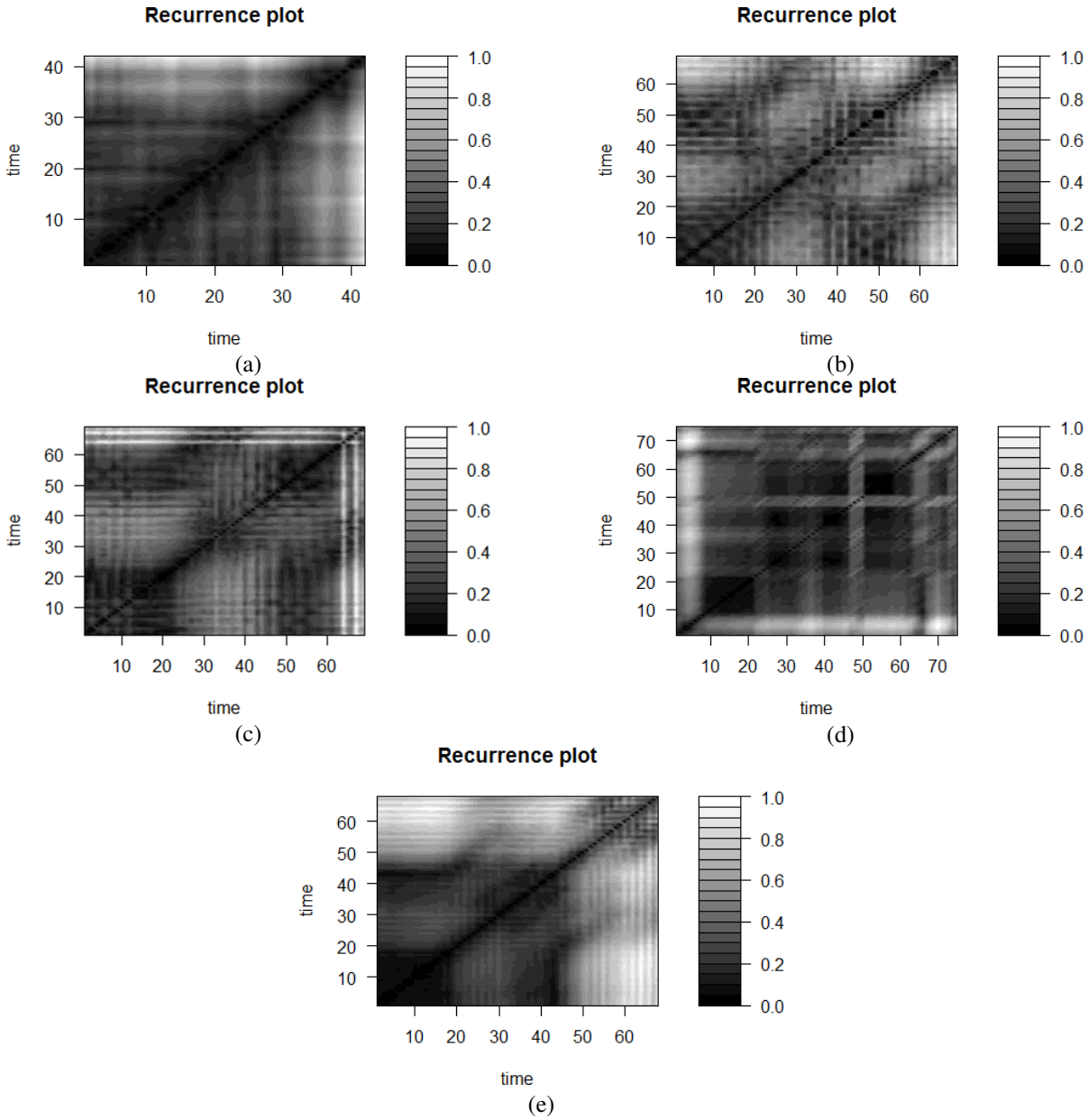

Figure 3: Recurrence plots of electric automobiles sales in China from January 2016 to June 2022: a) BYD, b) Chery, c) Gelly, d) Mercedes-Benz, e) Roewe.

of monthly sales volumes from January 2016 to June 2022 of five automobile companies: BYD, Chery, Geely, Mercedes-Benz and Roewe.

For the research, three methods of nonlinear dynamics were used, namely: traditional R/S-analysis – the method of normalized Hurst range, phase analysis and the method of recurrence plots.

As a result of applying the Hurst normalized range method, the property of trend stability of time series was revealed, which indicates the presence of long-term memory in them. Therefore, we can conclude that the time series of sales of electric automobiles in the Chinese market have a non-linear (fractal) nature. It follows that the use of forecasting methods based on the classical approach is not adequate and may lead to an unsatisfactory forecasting result. When choosing a method for predicting sales of electric automobiles and their parameters, it is necessary to take into account the presence of long-term memory and, preferably, its characteristics.

However, fractal analysis, which is based on the use of the Hurst normalized range method, allows

only qualitative conclusions to be drawn regarding the properties of the electric vehicle market as a whole, as well as the properties of the trend stability of each of the time series that were considered. The quantitative characteristics obtained by this method are averaged over the entire series. Therefore, to obtain differentiated characteristics of the identified memory, it is promising to research these time series using fractal analysis methods, which are based on the sequential R/S analysis algorithm (Perepelitsa and Maksyshko, 2012).

The use of phase analysis in a two-dimensional phase spase made it possible to identify the presence or absence of cyclicity in dynamics at some time intervals, to evaluate the characteristics of attractors (quasi-cycles) and their features for each agent in the Chinese electric automobiles market. The results obtained are the basis for further research in the direction of a more detailed research of the identified features in the dynamics due to decomposition the phase portrait into quasicycles, determining their characteristics, analyzing the dynamics of the overall dimensions of quasicycles and their centers of attraction.

The construction of recurrence plots in ρ-dimensional phase spase and their topological analysis made it possible to confirm the presence of attractor drift for all agents in the Chinese electric automobiles market. A gradual change in the parameters of the behavior of agents was also revealed.

Quantitative analysis of recurrence plots based on the calculation of measures of complexity of their structure (in particular, the percent recurrence (%REC) and the percent determinism (%DET) also made it possible to confirm the fractal (deterministic) nature of the nature of the dynamics of sales of electric vehicles in the Chinese market. It should be noted that at the moment the input data of the research are characterized by a short time series. This, obviously, affects both the possibilities, and the features, and the results of using the applied methods. However, their application – each separately and in combination – provides an opportunity to gain new knowledge about the characteristics of the dynamics in a new market that is rapidly developing and has prospects in the global economy – the market for electric vehicles.

The results of the research can be used to select relevant forecasting methods and their parameters.

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The Problem of Estimating the Sustainable Development of Technogenic Production System in According to Cognitive Factors in the Innovation Economy

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Keywords: Sustainable Development, Technogenic Production System, Cognitive Production Factors, Innovation Economy, Knowledge-Intensive Enterprise, Industry 4.0, Convergence, Stochastic, Human Capital.

Abstract: Development of integrated models based on the use of mathematical methods, models and innovative technologies to manage and predict the nonlinear dynamics of ecological, economic and socio-humanitarian systems in modern conditions of instability and crises is an urgent problem. Synthesis of integrated models taking into account humanitarian and cognitive variables to assess sustainable and safe development is also important and relevant. The article summarizes and develops the results of previous works of the authors to solve the problem of estimating the sustainable development of complex technogenic production systems, taking into account cognitive factors in the conditions of innovative economy. The integration model of sustainable development is presented as a family of models for creating integrated information systems of ecological, economic and socio-humanitarian management of various social and organizational systems and especially economic objects of anthropogenic nature to ensure sustainable and viable development. A cognitive model of nonlinear system dynamics is presented, taking into account the dynamics of the humanitarian component with management in general. Since innovative capital is wider than intellectual capital by its nature and content, the paper also presents a model of innovation capital dynamics for the eco-economic and socio-humanitarian system (EESHS). An extended integral model of nonlinear stochastic dynamics of EESHS in the innovation space is obtained. The basis and paradigms of fundamental research in the works of the authors are: systems of type "X", integral models and the problem of sustainable development, models such as "NMSSD" and systems such as "SEEHS", convergent technologies "NBIC" and "NBIC⊕SG".

1 INTRODUCTION

The relevance and need for basic and applied research in elaborating and solving sustainable development problems is defined by the 17 goals, which were adopted by all UN member states in 2015 as part of the 2030 Agenda for Sustainable Development, which sets out a 15-years plan to achieve them. Currently, there is some progress in many areas, but in general, actions to implement the goals have not yet reached the necessary pace and scale. These goals have also been adapted and accepted for implementation in Ukraine (Rep, 2017).

The work proposed by the authors is an extension of the results presented earlier in (Ramazanov and Honcharenko, 2021; Ramazanov et al., 2020).

2 MAIN RESULTS

Currently, the determining factors of a knowledge-intensive enterprise (KE) are not so much production capacity, but rather knowledge, know-how, research and development.

The theory of production factors (PF) by the beginning of XXI century became one of the actual research directions, covering the methodology of economic analysis and management of economic sub-

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jects. The main postulate of the theory of production factors is that the ratio of external factors of production and the internal state of the economic entity determines its strategic position in a complex and multidimensional market space, i.e. its organizational, economic and structural sustainability (Moiseev, 1981; Kolemaev, 2005; Krass and Chuprinov, 2006; Vorontsovsky and Vyunenko, 2016).

The main provisions of the modern theory of PF can be formulated as follows: organizational and economic sustainability of the economic entity is determined by the ratio of available factors of production and their effective management; competitive advantages of the economic entity depend on the availability (including ownership) of strategic resources; effective management of available factors of production is provided by organizational capabilities of KE; taking into account cognitive, stochastic, humanitarian and "NOT-" factors.

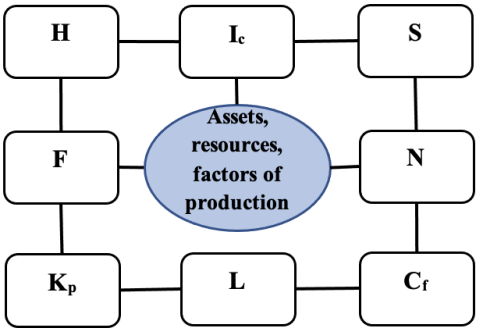
A logical question arises: what properties should the factors of production have, so that the innovative development of the KE could be effective, intensive and adaptive?

To answer this question, it is necessary to clarify the list of PF, which play a key role for the sustainable functioning and development of KEs, to introduce the concept and give a definition of cognitive factors of production; to develop a classification of cognitive factors of production, etc.

To implement this task, we will use the system paradigm, analyze the known concepts of PF and identify the main characteristics of cognitive production factors, which determine the organizational and economic sustainability of KE[1] (figure 1) (Ramazanov and Honcharenko, 2021).

Cognitive production factors (CPF). The analysis of the development of the theory of production factors and the emergence of their new types shows that the composition and role of production factors are most closely connected both with changes in production itself, and with the development of economic science, identifying and explaining the emergence and purpose of certain production factors by increasing opportunities for economic growth of knowledge-intensive enterprise.

Thus, according to the theory of human capital (the term was introduced by G. Becker (Makarov et al., 2009; Machlup, 1962; Milner, 2003)), the stock of knowledge, abilities and motivation embodied in a person contributes to the growth of human productive



S	*Social capital*
F	*Financial capital*
N	*Natural capital (land, water, etc.)*
K_p	*Physical capital (main production assets)*
L	*Labor resources (manpower)*
H	*Human / intellectual capital*
C_f	*Cognitive factors of production*
I_c	*Innovative capital*

Figure 1: "Octagon" of basic assets/resources that support the sustainability and safety of the system.

power. Human resources are to a certain extent similar to natural resources and physical capital, but in this interpretation they are divided into two parts. The unit of "human capital" is not the worker himself, but his knowledge. However, this capital does not exist outside of its bearer. And this is the fundamental difference between human capital and physical capital – machines and equipment.

By its economic essence, human capital is closer to the intangible fixed assets of an enterprise. According to the theory of human capital, investments in human beings are regarded as a source of economic development, no less important than "ordinary" capital investments. This means that an economic dimension is applied to a person.

The modern stage of KE development is characterized by qualitative changes in the types of socially significant human activity: labor characteristic of an industrial society is replaced by creativity in a post-industrial society. Machine technology gives way to "intellectual technology". As a result, knowledge and information become the leading factors of production, which leads to a decrease in the role of material factors of production. Radical changes in production relations have led to special requirements for the quality of human resources, highlighting their intellectual component and making them an independent factor of production.

Let us introduce the concept of cognitive produc-

[1] KE – knowledge-intensive enterprises of the high-tech sector of the economy. Knowledge-intensive enterprises (in other words, high-tech enterprises – HE) are technological leaders in the national innovation economy.

tion factor (CPF) – it is an embodied in an economic entity totality of knowledge, abilities, skills, which contribute to the growth of human productive power in the creation of an intellectual product demanded by the market.

The convergence of intellectual resources and information technology as a productive force causes the emergence of new types of factors of production – cognitive production factors (CPF, C_f) – which means specific, difficult to imitate resources of an industrial enterprise to create a product and added value, demanded by the market.

CPF are considered as a productive force arising from the convergence of human cognitive abilities and information technology.

Cognition as a scientific-cognitive action, is moving to a new quality, providing relevant knowledge for complex research. Artificial intelligence, neurocomputers, technologies of various interfaces based on the use of the properties of the human brain (Lukianenko and Strelchenko, 2021) – a fundamentally new environment of human productive activity. The use of cognitive principles in economics allows to bring the main production processes to an intellectually new level.

CPF provide internal (endogenous) opportunities for the development of industrial enterprises and, in fact, become one of the sources of endogenous economic growth (Kolemaev, 2005; Krass and Chuprinov, 2006). The management of CPF means the emergence in the practice of industrial enterprises of a specific type of organizational and economic activity associated with their identification, ranking, analysis, evaluation and monitoring at all stages of the reproduction cycle to achieve the goals of long-term economic growth.

The allocation of CPF as a new type of productive force necessitates the development of appropriate methods and models of their management, the practical implementation of which is possible due to the mechanism of integration into the overall management circuit of the industrial enterprise.

The effectiveness of methods used in the management of traditional factors of production is becoming less effective, since it does not take into account the dynamics of modern changes, the need to process a large amount of data, the structural complexity of management tasks, the need to use coordination mechanisms.

The study of theoretical and practical results of production factor management allowed us to conclude that CPF management should be integrated into the overall management circuit of a high-tech enterprise and be supported primarily by end-to-end activities implemented through appropriate business processes.

The increasing intellectualization of industrial production contributes to the fact that the distinctive features of enterprises become:

- significant individualization of products in conditions of high flexibility of high-volume production;
- the modern vector of civilizational development of society is represented by the intensive spread of global technologies: nano-, bio-, information and communication technologies. Cognitive technologies refer to the technologies of the global level, the transformative effect of which gives a new quality of interacting elements and leads to the formation of a fundamentally new technological platform for economic development;
- integration of consumers and manufacturers in end-to-end processes of the entire product lifecycle and value chain;
- integration of information and data within production networks, reflecting all aspects of requirements, design, development, production, logistics, operation, service, etc., i.e. creation of "production intelligence";
- globalization of product/goods development teams, as the complexity of products requires a variety of competencies;
- formation of a networked production "ecosystem" through cooperation and reduction of barriers between enterprises and customers;
- development of cloud technologies as a way to implement customized production on demand; use the production capabilities of virtual production networks based on united production sites, and support them with special software;
- isolation and accumulation of intangible functions, such as research and forecasting of the market and demand, formation of the product concept, formation of technical requirements, etc.; since intangible components take an increasing share in the cost and price of the finished product;
- formation of the market value of enterprises due to the knowledge of employees, know-how, knowledge-intensive technologies, inventions, industrial designs and other intangible assets. The qualitative change of production factors puts forward a set of interrelated tasks for industrial enterprises (Krass and Chuprinov, 2006; Vorontsovsky and Vyunenko, 2016);
- the integration into Industry 4.0, increasing the continuity and flexibility of production, the transition to flexible production systems that ensure

the adaptation of the production infrastructure to innovative activities, changes in market requirements demand different approaches to the composition and configuration of key factors of production (Kobets and Yatsenko, 2019);

- increased consistency in the duration and productivity of all interrelated subdivisions of industrial enterprises causes the accounting of results not only at the place of application of production factors, but also in related units from the perspective of their impact on the economic performance of enterprises;
- rational increase in the growth of R&D costs, which ensures the implementation of scientific and technological policy directly in the process of scientific and production activities, determines the assessment of their relationship with the share of revenues from new types of products;
- the uncertainty of the economic environment, high risks in the development of innovative products create the preconditions for the development of economic-mathematical models that are adequate to the object of research and improve the quality of the effectiveness of industrial enterprises.

Thus, sustainable economic growth and development of modern industrial enterprises determines not so much the number of personnel, but the presence of workers who are able to conduct scientific and technological development at the modern level, to create competitive products and services on their basis, to propose new ways of organizing production, to determine the process of forming new trends in technological development in the market environment. In this regard, we need a different system of productive forces, surpassing the capabilities of industrial type of production and other ways of combining human and material labor.

The convergence of intellectual resources and information technologies as a productive force causes the emergence of new types of production factors – cognitive factors of production – which are understood as specific, difficult to imitate resources of an industrial enterprise that allow creating a product that is in demand by the market.

Cognitiveness, as a scientific and cognitive action, is moving into a new quality, providing appropriate knowledge for comprehensive research. Artificial intelligence, neurocomputers, technologies of various interfaces based on the use of the properties of the human brain are a fundamentally new environment for human production activities. The use of cognitive principles in the economy allows you to bring the main production processes to an intellectually new level.

Cognitive production factors provide internal opportunities for the development of industrial enterprises and, in fact, become one of the sources of endogenous economic growth (Kolemaev, 2005; Krass and Chuprinov, 2006; Vorontsovsky and Vyunenko, 2016). Cognitive production factors management means the emergence in the practice of industrial enterprises of a specific type of organizational and economic activity related to their identification, ranking, analysis, evaluation, monitoring at all stages of the reproduction cycle in order to achieve the goals of long-term economic growth.

The identification of cognitive factors of production as a new type of productive force necessitates the development of appropriate methods and models of their management, the practical implementation of which is possible due to the mechanism of integration into the overall control loop of an industrial enterprise (Ramazanov and Honcharenko, 2021; Ramazanov et al., 2020; Pankratov, 2017; Gorlacheva, 2020).

So, cognitive production factors (CPF, C_f) – are the result of the convergence of intellectual resources / intellectual capital and information technology:

"IR/IC" & "IT",

where & – here is a conditional symbol of convergence.

Cognitive basis of high-tech activity, which includes the unity of knowledge, experience, creativity and information technology. Structural elements of CPF are: knowledge, experience, creativity and skills in the use of information technology, i.e. *CPF – is a tuple <knowledge, experience, creativity, level of use of IT, ...>.*

One of the variants of correlations of cognitive production factors (CPF), human capital (HC) and intellectual capital (IC) by three comparison parameters.

1. Structural elements:
   - CPF: Knowledge, experience, creativity, skills, in the use of information systems and technology.
   - HC: Level of education, health status.
   - IC: Market assets, human assets, intellectual property, infrastructure assets.
2. Methods of evaluation and measurement:
   - CPF: Indicator based on up-to-date financial and accounting statements.
   - HC: Aggregated indices, the calculation of which requires an extensive information base.

- IC: Ratio of market value to book value; Intellectual coefficient of value added.

3. Correlation with performance results:
   - CPF: Production function.
   - HC: The balanced scorecard system.
   - IC: Aggregate of IC and capital involved.

Note that the presented list of CPF is not exhaustive, it can and should be supplemented and improved.

So, CPF is a set of both active and intensional, as well as tangible and intangible factors of production:

- tangible-active can include those CPF, which are embodied and directly used in the economic turnover. These include local computer networks for information exchange, flexible manufacturing systems (FMS), simple/complex robots, automated information storage and retrieval systems, planning systems (ERPI, ERPII), design systems (CFD, CAE, PLM), electronic document management systems, vision systems;
- intangible assets include objects of intellectual property: know-how, technical solutions, licenses, patents, databases, information about customers and suppliers, etc;
- material-intentional cognitive factors include the potential use of advanced technologies, such as augmented reality technologies, artificial intelligence technologies: Internet of Things technologies, big data, cloud computing, deep learning, 5G, etc;
- intangible-intentional include personal characteristics of employees, experience, culture of thinking, ability to learn, creativity, insight, intuition, level of education, level of digital literacy, ability to cognitive activity, analysis, reflection, self-regulation, communication abilities, compliance with ethical and social norms.

Let us also note now that innovation capital is one of the most important and specific forms of capital, reflecting the ability of industrial enterprises as participants in the innovation cluster to generate income due to the development of innovative activity and acquisition of a special status due to the dynamics of innovation potential as an institution capable of transformation into capital as a result of the synergistic effect of interaction between economic entities in the process of innovation development. Innovation capital from the point of view of classical economic theory is characterized by three essential features, namely, it is a product of past labor, the role of which is played by innovation potential; it is a production or product stock in the form of innovations produced and ready for implementation, as well as innovations requiring further improvement and innovations that can be accumulated in the form of innovation potential; it is a source of income based on the effective commercialization of innovation (Milner, 2009; Geets and Seminozhenko, 2006).

By its nature and content, innovation capital is wider than intellectual capital, which according to the concept presented in the works of Milner (Milner, 2009, 2003), consists of three elements: 1) human capital; 2) organizational (structural) capital; 3) consumer capital. Machlup (Machlup, 1962) in 1966, analyzing the processes of knowledge production and dissemination in the United States, without downplaying the role and importance of material production, reasonably proved that the economic development of the "new age" is determined not so much by the availability and productivity of material resources as by the availability and speed of information distribution in society and the amount of intellectual capital (Moiseev, 1981; Kolemaev, 2005; Vorontsovsky and Vyunenko, 2016).

Let us present a cognitive model of the nonlinear dynamics of the system, taking into account the dynamics of the humanitarian component with control (as an extension of the integral model (Ramazanov and Honcharenko, 2021; Ramazanov et al., 2020)), in general terms it can be represented as stochastic differential equations:

$$\frac{dH_{\mathcal{U}}(t)}{dt} = \chi_{+}H^{+}_{\mathcal{U}}(t) - \chi_{-}H^{-}_{\mathcal{U}}(t) + \sigma_{H_{\mathcal{U}}}(H_{\mathcal{U}},t)dW_{H_{\mathcal{U}}}(t) + b_{H_{\mathcal{U}}}U_{H_{\mathcal{U}}}(t). \quad (1)$$

$$\frac{dC_f(t)}{dt} = \vartheta_{+}C^{+}_{f}(t) - \vartheta_{-}C^{-}_{f}(t) + \sigma_{C_f}(C_f,t)dW_{C_f}(t) + \vartheta_{C_f}U_{C_f}(t). \quad (2)$$

The model of the dynamics of innovativeness of the eco-economic and socio-humanitarian system (EESHS) can also be represented in the form of an equation of dynamics:

$$\frac{dI_c(t)}{dt} = \varsigma_{+}I^{+}_{c}(t) - \varsigma_{-}I^{-}_{c}(t) + \sigma_{I_c}(I_c,t)dW_{I_c}(t) + \vartheta_{I_c}U_{I_c}(t). \quad (3)$$

In equations (1)-(3) the variable $H_{\mathcal{U}}(t)$ is a humanitarian variable, $C_f(t)$ – cognitive variable, $I_c(t)$ – variable (level) of innovativeness in the integral model EESHS [2]; $\chi_{+},\chi_{-},\vartheta_{+},\vartheta_{-},\varsigma_{+},\varsigma_{-}$ – parameters, and other designations are given in the same work.

So, supplementing the system of equations of the integral model (Ramazanov and Honcharenko, 2021; Ramazanov et al., 2020; Halitsin and Ramazanov, 2016) with equations (1) – (3) we obtain an extended

(generalized) integral model of nonlinear stochastic dynamics of EESHS in the innovation space.

The generalized production and technological function (PTF) can now be represented as:

$$Y(t) = F[K(t,L(t),H(t),N(t),\Phi(t), S(t),I_c(t),C_f(t);\vec{c}]. \quad (4)$$

It can be used to study sustainable development.

In the general case, the integral level of sustainable development can be represented as a nonlinear function:

$$Y_{sdl}(t) = F_{sdl}[]K(t),L(t),H(t),N(t), \Phi(t),S(t),I_c(t),C_f(t),\vec{c}]. \quad (5)$$

Private versions of the PTF model:

a) Mankiw-Romer-Weil model. Option of accounting for human capital H in the production function (PF), along with physical capital (K), labor (L) and natural (N) resources:

$$Y(t) = K^{\alpha}(t) \cdot H^{\beta}(t) \cdot [A(t) \cdot L(t)]^{1-\alpha-\beta}, \quad (6)$$

where $\alpha,\beta > 0$, $\alpha+\beta < 1$; H; $A(t)$ – function of scientific and technological progress. Note that α – is a part of capital provided by investment growth (capital costs); β is similar.

b) Model of accounting for all fixed assets:

$$Y(t) = A(t)K^{\alpha}(t) \cdot L^{\beta}(t) \cdot H^{\gamma}(t) \cdot S^{\rho}(t) \cdot \Phi^{q}(t) \cdot N^{\tau}(t) \cdot I^{\nu}(t), \quad (7)$$

where $\alpha,\beta,\gamma,\rho,q,\tau,\nu > 0$ and $\alpha+\beta+\gamma+\rho+q+\tau+\nu = 1$.

The following notations are also used here: K – physical capital, L – labor (labor), H – human capital, S – social capital, Φ – financial capital, N – natural resources (land, water, etc.), $A(t)$ is a function of the level of scientific, technical and technological development, for example, $A(t) = aT^{S}(t)$, where $T(t)$ – volume of innovative technologies (resources).

In (Ramazanov et al., 2020), the equation of the dynamics of the potential of the R&D sector in the integral model is presented as:

$$\frac{d}{dt}[\dot{\varphi}(t)] - \delta_{\varphi}\varphi(t) = G[\varphi(t)]^{\gamma_1} \cdot [\alpha^1_{L_1}(t)L_1(t)]^{\gamma_2} \cdot [\alpha^1_K(t)K(t)]^{\gamma_3} \cdot [s(t)]^{\gamma_4} + \sigma_{\varphi}(\varphi,t)e_{\varphi}(t), \quad (8)$$

where $\varphi(t)$ – stock of knowledge and technologies in the economy – the number of inventions that have not lost their relevance by the year t; $\dot{\varphi}(t)$ – increase in the stock of knowledge per unit of time – the number of new inventions per year t minus obsolete; $L_1(t)$ – the volume of skilled (more precisely – highly skilled) labor (skilled labor force with qualifications, i.e. the product of the number of skilled workers $L_1(t)$ and the level of qualification of the average employee $h(t)$, i.e. $h(t)L_1(t)$); s(t) – social index; δ_{φ} – the rate of knowledge attrition due to its obsolescence $\delta_{\varphi} > 0$; $\alpha^1_{L_1}(t)$ – share of skilled labour employed in the R&D sector $0 \le \alpha^1_{L_1}(t) \le 1$; $\gamma_1,\gamma_2,\gamma_3$ – static parameters $0 \le \gamma_1 \le 1$, $0 \le \gamma_2 \le 1$, $0 \le \gamma_3 \le 1$; G – scale parameter: $G > 0$. Here $\{e_{\varphi}(t), t \in T\}$ – white noise with continuous time; $\sigma_{\varphi}(\varphi,t)$ – volatility coefficient.

From (Ramazanov and Honcharenko, 2021; Ramazanov et al., 2020) we have a more general equation of dynamics, i.e. the equation of the STP index (STP weight), which shows the growth and efficiency of the use of labor, capital and technology in production, i.e. $\tau(t)$:

$$\frac{d}{dt}[\dot{\tau}(t)] + \delta_{\tau}\tau(t) = B[\dot{\varphi}(t) + \delta_{\varphi}\varphi(t)]^{\beta_1} \cdot [\dot{\sigma}(t) + \delta_{\sigma}\sigma(t)]^{\beta_2}[\dot{s}(t) + \delta_s s(t)]^{\beta_3}[\dot{z}(t) + \delta_z z(t)]^{\beta_4} \quad (9)$$

where $\dot{\tau}(t)$ is the increase of the STP index caused by the change in the number of advanced production technologies used in production per unit of time, δ_{τ} – the rate of decrease of the STP index due to the obsolescence of advanced production technologies, $\delta_{\tau} > 0$; $\beta_1,\beta_2,\beta_3,\beta_4$ – static parameters, $0 \le \beta_1 \le 1, 0 \le \beta_2 \le 1, 0 \le \beta_3 \le 1, 0 \le \beta_4 \le 1$; B – scale parameter; $B > 0$.

Note that $\tau(t)$ – STP index, dependent on the number of advanced production technologies $w(t)$ and used in production, for example, $\tau(t) = [w(t)]^d$, where $d - const$.

Now in this generalized and integral variant we can use the conditions of development stability from (Ramazanov and Honcharenko, 2021; Ramazanov et al., 2020; Zgurovsky, 2006).

This construction of the indicator will reflect the importance of each of the considered components: eco-economic and socio-humanitarian subsystems (spheres) in the performance of the objective function. A change in any of the private indicators leads to a change in the value of the aggregate indicator and captures a change in the steady state of the region. In the general case, all indicators change over time, i.e. have a certain dynamic.

Simple conditions for sustainable development (SD) are defined as follows.

1) Condition of weak stability:

$$\frac{dF[\cdot]}{dt} \ge 0 \quad or \quad F_{t+1}[\cdot] \ge F_t[\cdot], \quad (10)$$

where

$$F_t[\cdot] = F[K(t),L(t),H(t),N(t), \Phi(t),S(t),I_c(t),C_f(t),\vec{c}] \quad (11)$$

2) Condition of strong stability:

$$\frac{dF[\cdot]}{dt} \geq 0 \quad ,N = N^C + N^S \quad and \quad \frac{dN^C}{dt} \geq 0, \quad (12)$$
$$or \quad N^C_{t+1} \geq N^C_t, \quad N = 1...4$$

where N^C – critical part of natural capital, and N^S – natural capital, which can be replaced by artificial.

For example, given critical natural capital N^C, sustainable development can be supplemented by a time limit on depletion of this value. For a time-decreasing production function, the arguments of which are aggregated variables: labor – L, capital – K and natural – resource N, we will have the ratio:

$$F_t(K,L,N) \leq F_{t+1}(K,L,N) \quad (13)$$

or, in the general case:

$$F(K(t),L(t),H(t),N(t),\Phi(t),S(t),I_c(t),C_f(t),\vec{c}) \leq$$
$$F(K(t+1),L(t+1),H(t+1),N(t+1),\Phi(t+1),$$
$$S(t+1),I_c(t+1),C_f(t+1),\vec{c}) \quad (14)$$

And it also requires compliance with the condition of not decreasing in time the value of N^C, i.e. $N_t = N^C_t + N^S_t$, as well as the condition of partial replacement of natural capital N by artificial N^S (or non-renewable resource for renewable resource): $N_t = N^C_t + N^S_t$.

The integrated level of sustainable development for all capital (resources) can be defined, for example, in the case of linear dependence as:

$$Y_{sdl}(t) = c_1K(t) + c_2L(t) + c_3H(t) + c_4N(t) +$$
$$c_5\Phi(t) + c_6S(t) + c_7I_c(t) + c_8C_f(t), \quad (15)$$

where $c_1, c_2, c_3, c_4, c_5, c_6, c_7, c_8$ are weight (normalizing and scaling) coefficients.

3 CONCLUSION

The article summarizes and develops the results of the authors' earlier works in solving the problem of estimating the sustainable development of technogenic production system, taking into account cognitive factors in the context of innovation economy.

Integration model of sustainable development is presented as a family of models for creating integrated information systems of eco-economic and socio-humanitarian management of various social and organizational systems and especially economic objects of anthropogenic nature to ensure sustainable and viable development.

A cognitive model of nonlinear system dynamics is presented, taking into account the dynamics of the humanitarian component with management in general. Since innovative capital is wider than intellectual capital by its nature and content, the paper also presents a model of innovation capital dynamics for the eco-economic and socio-humanitarian system (EESHS). An extended integral model of nonlinear stochastic dynamics of EESHS in the innovation space is obtained.

The transition to an information society leads to a change in the structure of total capital in favor of human capital, an increase in intangible flows, knowledge flows, intellectual and innovative capital. The problem of sustainable development based on 8 important assets that support the sustainability and viability of EESHS was investigated.

The use of these methods will increase the efficiency of solutions in the management of technogenic production systems, will increase the efficiency of the use of innovations and will identify areas of innovation strategies of the regions.

The presented result requires further research, generalizations and computer experiments on real data.

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Modelling the Design of University Competitiveness

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Abstract: In the post-industrial knowledge economy, the key role in the generation and dissemination of innovations is played by universities, where global intellectual capital is concentrated. Today, universities are becoming the drivers of digital transformation of science, business, countries and society as a whole. In the latest paradigm of development, based on the generalization of modern theoretical trends, the scientific and practical problems as well as prospects for the development of universities are highlighted and the prerequisites, imperatives and factors of their competitiveness are revealed. The research also focuses on modelling of university competitiveness parameters with the clustering of countries on the basis of Kohonen maps and assessment of the level of significance of normalized parameters. The organizational design of a competitive model of the university as well as key factors of its success in the system of open science, education and innovation are proposed.

1 INTRODUCTION

In the global highly competitive educational environment, under the influence of ultra-dynamic digitalization, traditional models and organizational structures of universities are being devalued. Innovative network-type models are becoming relevant, and the choice of breakthrough, catch-up or adaptation strategies depends primarily on the competitive status of the university in the global market of educational services.

The global transformation of university education raises new challenges for state authorities in the field of education and university administrations to ensure their competitiveness in the international market of educational services. In the context of increasing the efficiency of the university management process in modern globalization conditions, the tasks of assessing its international competitiveness arise.

This problem has received close attention in scientific research in recent years. Many publications are focused on the analysis of generally accepted methods for assessing the competitiveness of universities and their ranking, comparing these methods, key indicators, modelling principles and identifying their weaknesses.

Avralev and Efimova (Avralev and Efimova, 2015) have conducted a survey of students over the years, which showed that place in the university rankings is an increasingly important criterion for students when choosing a university. At the same time, most researchers criticize the widely used rating systems. Thus, Sayed (Sayed, 2019) demonstrates that according to some of the world's leading ranking systems, a university may be at the top of the ranking, while in others it may not be ranked at all. Many researchers note (Anowar et al., 2015; Marginson and van der Wende, 2016) that most of the global university rankings focus primarily on research, while at the same time not paying enough attention to the quality of teaching, student competences and learning outcomes, social responsibility, etc.

At the same time, most scientists agree that the main criteria that determine the competitiveness of universities are research and teaching (Dimitrova and Dimitrova, 2017; Sayed, 2019; Taylor and Braddock, 2008; Tee, 2016). In addition, some authors emphasize the importance of other criteria, such as international cooperation with university research networks, involving foreign teachers and students, increasing international citation (Avralev and Efimova, 2013; Chládková et al., 2021; Deem et al., 2008), quality of pedagogical staff (Chládková et al., 2021), so-

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cial and environmental responsibility (Lukman et al., 2010), digitization of all university functioning processes (Kucherova et al., 2021; Lukianenko et al., 2020; Sannikova et al., 2021), expenditure on higher education per student (Satsyk, 2014), employability of graduates (Jurášková et al., 2015b,a). The importance of cooperation with business to improve the competencies and employability of students and, as a result, the competitiveness of the university, is emphasized in the papers (Jurášková et al., 2015b; Lukianenko et al., 2020; Stoimenova, 2019; Teixeira et al., 2020).

As can be seen from the above review, all these works are aimed either at the analysis and criticism of known rating systems, or at the study of factors that affect the competitiveness of universities, or, at most, at the creation of own methods for calculating university ratings, which are based on the simplest statistical methods.

There are works in which advanced artificial intelligence technologies are used to analyze and rank universities according to certain areas of activity. For example, in (Kucherova et al., 2021) developed a fuzzy logic model for assessment and ranking of universities' websites by criterion of usability.

However, the analysis of developments in this direction did not allow to identify studies on the modeling of university competitiveness based on cutting-edge artificial intelligence technologies, moreover, which would not be based in the rating on the expertly set weights of the evaluation criteria.

2 MODELING METHOD

Solving the task of evaluating the international competitiveness of universities is associated with a number of specific problems, because competitiveness does not have generally accepted evaluation indicator, units or measurement scales. This is a subjective category that depends on many factors affecting it. Moreover, the set of these factors and the degree of influence of each of them are also not determined by any objective circumstances and can be chosen by analysts and researchers depending on their own understanding of the essence of the category "competitiveness of universities", the development of the educational process, their own priorities, etc. All this imposes a significant imprint of subjectivism on the formation of methods of their evaluation.

It is possible to reduce the dependence on the subjective opinions of individual experts with the use of special modeling methods capable of revealing regularities in the structure of an array of heterogeneous data, when there are no predetermined values of the resulting indicator, such as for the international competitiveness of universities.

Under such conditions, the clustering approach is the most appropriate means of searching for hidden regularities in sets of explanatory variables. The main feature of this approach is that with its application, objects that belong to one cluster are more similar to each other than to objects that are included in other clusters. As a result, it becomes possible to form fairly homogeneous groups of researched objects that are characterized by similar properties.

There is a wide range of cluster analysis methods: K-means (Hartigan and Wong, 1979), K-medoids (Kaufman and Rousseeuw, 1990), Principal Component Analysis (Jolliffe, 2002), Spectral Clustering (Von Luxburg, 2007), Dendrogram Method (Sokal and Rohlf, 1962), Dendrite Method (Caliński and Harabasz, 1974), Self-Organizing Maps – SOM (Kohonen, 1982, 2001), Density-Based Spatial Clustering of Applications with Noise – DBSCAN (Schubert et al., 2017), Hierarchical DBSCAN – HDBSCAN (Campello et al., 2013), Ordering Points to Identify the Clustering Structure – OPTICS (Ankerst et al., 1999), Uniform Manifold Approximation and Projection – UMAP (McInnes and Healy, 2018), Balanced Iterative Reducing and Clustering Using Hierarchies – BIRCH (Zhang et al., 1996), etc.

Each of these methods has its advantages and areas of application and tasks, where it reveals itself in the best way. Experimental studies on comparative analysis of the effectiveness of various clustering methods are described, in particular, in scientific works (Kobets and Novak, 2021; Kobets and Yatsenko, 2019; Subasi, 2020; Velykoivanenko and Korchynskyi, 2022).

Taking into account the capabilities of each of the mentioned methods and the specifics of this study, the Kohonen self-organizing maps toolkit was used to cluster countries by the level of competitiveness of universities, which, in addition to forming homogeneous groups of researched objects, provide a convenient tool for visual analysis of clustering results. In particular, in contrast to other clustering methods, the location of an object on the Kohonen map immediately indicates to the analyst how developed the investigated property is compared to others, because the best and worst objects according to the analyzed indicator are located in opposite corners of the self-organizing map.

The result of constructing the Kohonen map is a visual representation of a two-dimensional lattice of neurons that reflect the organizational structure of the countries of the world, forming clusters in which

countries are similar to each other according to the group of indicators of evaluating the competitiveness of universities (figure 1).

The Kohonen self-organizing algorithm is a clustering method that reduces the dimension of multidimensional data vectors. It can be used to visualize clusters and to detect nonlinear patterns in input data structures. The main feature of such neural networks is unsupervised learning, when information about the desired network response is not needed to correctly set the parameters. In this study, self-organizing maps are used to summarize a complex set of data and clustering of countries by indicators that have the greatest impact on the international competitiveness of universities.

Thus, each neuron of the Kohonen layer receives information about the research object in the form of a vector $\mathbf{x}$, which consists of n explanatory variables (in our case, these are the characteristics that determine the competitiveness of universities). When a new data vector arrives at the input layer of the network, all neurons of the self-organization map participate in the competition to be the winner. As a result of such a competition, the winner is the neuron

$$o = \operatorname{argmin}\left\{\left\|\mathbf{x} - \mathbf{w}^j\right\|\right\} \quad (1)$$

that is more similar to the input data vector than others, usually by Euclidean distance:

$$\left\|\mathbf{x} - \mathbf{w}^j\right\| = \sqrt{\sum_{i=1}^{n}\left(x_i - w_i^j\right)^2}, j = \overline{1,K} \quad (2)$$

where $\mathbf{x}$ is a vector of input data consisting of indicators $\{x_1,\ldots,x_i,\ldots,x_n\}$ that describe the objects under study; $\mathbf{x}^j$ is the vector of parameters of j^{th} neuron of the Kohonen map, which consists of elements $\{w_1^j,\ldots,w_i^j,\ldots,w_n^j\}$; K is the number of neurons of the Kohonen map.

After determining the neuron-winner, we adjust the vector of its parameters and its neighbors according to the input vector:

$$\mathbf{w}^j(t+1) = \mathbf{w}^j(t) + \alpha(t)\cdot h_{oj}(t)\cdot\left[\mathbf{x}(t) - \mathbf{w}^j(t)\right], j = \overline{1,K} \quad (3)$$

where $\alpha(t)$ is the rate of learning ($0 < \alpha(t) \leq 1$), which decreases with each learning epoch t; $h_{oj}(t)$ is the strength of mutual influence for any pair of neurons o and j, determined as a function (usually Gaussian) of the distance between them on the map topology:

$$h_{oj}(t) = \exp\left[-\frac{\|\mathbf{r}_o - \mathbf{r}_j\|^2}{2\cdot\sigma^2(t)}\right] \quad (4)$$

where $\mathbf{r}_o$, $\mathbf{r}_j$ are the two-dimensional vectors of coordinates of geometric location of the neuron-winner o and the j^{th} neuron on the map; $\sigma(t)$ is the effective width of the topological neighborhood (a specially chosen function of time that monotonically decreases in the learning process).

In the process of self-organization of the Kohonen map, the topological neighborhood narrows. This is caused by a gradual decrease in the width of the function $\sigma(t)$. The neuron-winner is located in the center of the topological neighborhood. It affects neighboring neurons, but this effect decreases with increasing distance to them according to (4). As a result, closely located map nodes acquire similar characteristics.

The result of the learning process will be the tuning of parameters of the Kohonen layer neurons, which will correspond to different examples from the training set. Thus, the self-organization of the structure of the Kohonen map is carried out, which acquires the ability to combine multidimensional data vectors in a cluster by identifying similar statistical characteristics in them. As a result, the initial high-dimensional space is projected onto a two-dimensional map. Since self-organization maps are characterized by the generalization property, they can recognize input examples on which they have not previously been tuned – the new input data vector corresponds to the map element to which it is mapped.

3 COLLECTION OF DATA FOR MODELING

In order to correctly identify regularities in the development of the scientific and educational sphere, it is necessary to select the key properties that characterize the processes under study, taking into account the task. That is, it is necessary not only to choose the maximum possible set of characteristics of the objects of study, but to form a set of those features that describe the most significant aspects of activity in the context of the analysis. In this case, the selected features will make it possible to group the studied objects or processes according to their similarity. That is, if the task of analyzing the competitiveness of universities is being solved, then it is necessary to determine a set of characteristics of countries that will influence this indicator. And as a result of clustering the countries of the world according to these characteristics, we will get a number of clusters, each of which will group countries with a similar level of international competitiveness of universities (since they will have fairly close values of the characteristics that determine this competitiveness).

Therefore, we will conduct an analysis of publicly available databases that contain information on indi-

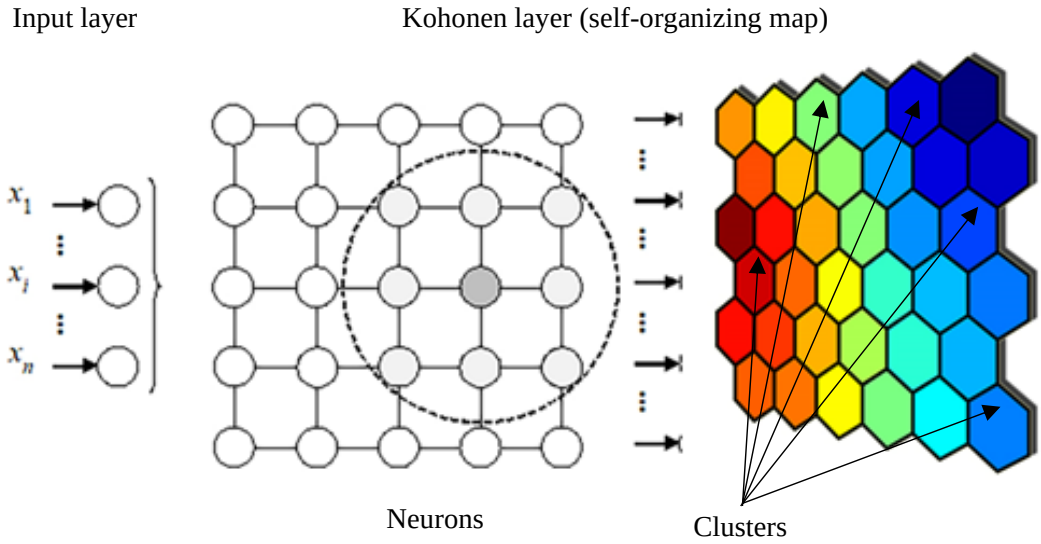

Figure 1: Visual representation of clusters on the self-organizing map (Matviychuk et al., 2019).

cators that can influence the level of competitiveness of universities.

Thus, the World Bank's "World Development Indicators" database contains the ranking of the world's countries by the level of "Government expenditure on education, total (% of GDP)" indicator (The World Bank, 2022). The indicator is calculated annually (for 266 countries) based on data from national statistics and international organizations, including data from the UN. Information on individual countries has been available in this database since 1970, in the last decade the data is presented quite fully, but only until 2018 (later data by countries is much less). Other indicators presented in this database are much poorer and less related to higher education.

In the Human Development Reports of UNDP (United Nations Development Programme, 2022) there are data for 195 countries for 2021 according to the indicators: "Human Development Index (HDI)" (both in general and by male and female sexes, in addition, by this indicator also shows the dynamics and increases in dynamics since 1990), "Government expenditure on education, % of GDP", "High-skill to low-skill ratio", "Research and development expenditure, % of GDP" (during 2014-2018), "Ratio of education and health expenditure to military expenditure" (during 2010-2017), "Foreign direct investment, net inflows, % of GDP", "International student mobility, % of total tertiary enrollment", indicators of employment and unemployment both in general and among young people, migrants, population by age group, etc.

The Global Competitiveness Index from the World Economic Forum for 2019 (World Economic Forum, 2019) can also be informative in assessing the international competitiveness of the country's universities. On this resource, this index is given for 141 countries. Later, in 2020, the Global Competitiveness Index has been paused.

Another resource with information on competitiveness is the annual reports of the European Commission (European Commission, 2022), in particular in the areas of: "Competitiveness & Innovation", which contains separate reports and the following sections: "Global Innovation Index", "Global Attractiveness Index", "Global Talent Competitiveness Index", "Elcano Global Presence Index", "Innovation Output Indicator"; "Learning & Research", which presents reports: "European Skills Index", "European Lifelong Learning Indicators (ELLI-Index)", "Higher Education Rankings", "Composite Learning Index".

The work "Global Talent Competitiveness Index: 2019" (Lanvin and Monteiro, 2019) contains integrated assessments and ranking places of countries for a number of top-level indices, as well as for basic indicators.

To assess the competitiveness of world universities, the resource (UNIVERSITAS 21, 2021) can be useful, which provides fairly detailed country-level aggregated information on the research and educational activities of universities in 50 countries for 2020. Here are the indicators grouped into four generalized categories – "Resources", "Environment", "Connectivity", "Output". Each of these categories consists of a set of basic indices, all of which are listed in the header of the table 1.

In addition, we add to the database the overall competitiveness score and rank number in the general list (these indicators will not be taken into account

Table 1: Indicators of evaluation of international competitiveness of countries' universities.

	OVERALL RANKING				RESOURCES 2020 SCORES					ENVIRONMENT 2020 SCORES					CONNECTIVITY 2020 SCORES					OUTPUT 2020 SCORES								
Country	Rank 2020	Rank 2019	Score 2020	Score 2019	Government expenditure on tertiary education as a percentage of GDP	Total expenditure on tertiary education as a percentage of GDP	Total expenditure per student USD PPP	Expenditure in tertiary institutions for R&D as a percent of GDP	Expenditure in tertiary institutions for R&D per head of population	Proportion of female students	Proportion of female academic staff	Data quality	Qualitative index of environment	WEF Survey	Proportion of international students	Proportion of articles with international collaborators	Webometrics VISIBILITY index divided by population	Rating of knowledge transfer between university and companies	Percentage of university research publications co-authored with industry	Total number of documents produced by higher education institutions	Total documents produced per head of population	Average impact of articles	Weighted Shanghai ranking scores for universities per head of population	Shanghai scores for best three universities	Tertiary enrollment rates	Percentage of population aged 24-64 with a tertiary qualification	Number of researchers in the nation per head of population	Unemployment rate of the tertiary educated compared with school leavers
Argentina	40	38	46	45,1	56,7	48,4	13,8	13,4	4,7	100	97,1	100	67,8	51,3	9,1	52,4	7	54,1	19,5	2,1	6,2	45,9	2,6	13,1	90	61,6	14,9	30,9
Australia	9	8	82,2	80,9	37,7	70,6	42,9	64	51,2	100	91,3	100	98,1	81,9	78,9	72,8	56	68,1	41,4	15,9	85,3	84,3	76,8	39,3	100	79	55	32,6
Austria	12	12	79,3	77,2	81,9	64,8	48,7	68,6	63,7	100	84,7	100	72	68,3	63,1	86,9	54	84,8	100	3,3	49,4	86	57	22	85,1	56,5	62,5	31,3
Belgium	13	13	75,6	73,6	63,8	55,4	48,3	53	45	100	97,1	100	75,8	82,2	31,8	89,3	28,4	82,5	78,8	4,8	56,6	94,2	51,4	31,4	79,7	70,2	59,9	39,1
Brazil	41	40	45,6	44,1	49,9	66,5	37,9	n.a.	n.a.	100	91,4	88,6	63,8	41,8	0,9	43,8	6,9	40,3	26,2	11,6	7,5	45,3	3,8	21,2	51,3	31,8	10,7	39,7
Bulgaria	45	44	42,7	41,8	32,3	40,3	17,8	4,3	1,6	100	97,9	93,2	53,1	54,7	16,8	57,5	10,9	46	44,3	0,8	14,6	55,2	3,3	2,7	71,2	38,1	25,8	45,2
Canada	7	6	83,2	81,9	62,5	86,8	62,9	63,6	53	100	88,6	90,9	73,3	87,1	47,4	68,8	69,2	86,3	59	17,2	62,6	82	44	42,9	88,2	100	51,8	33,7
Chile	31	32	54,3	51,3	48,4	100	22,3	14,8	6	100	85,1	100	81,4	54,8	1,4	81,6	14,3	62,3	28,3	2,2	16,1	63,4	8,2	11,8	88,5	43,5	6,1	30,2
China	26	27	56,8	54,7	42,5	50,7	20	15	4,4	100	n.a.	88,6	76,6	73	1,3	34,1	8,4	65,9	32	70,7	6,8	59,3	7,5	39,6	49,1	16,7	15	n.a.
Croatia	43	43	43,6	42,1	49,9	36,8	18	24,9	11,2	100	97,8	93,2	47,3	47	1,6	58,3	11	35,5	50,8	0,9	30,4	52,9	17,2	8	66,5	39,2	22,6	31,2
Czech Rep.	29	26	54,8	55,2	36,3	35,1	26,6	34,4	22,2	100	76,9	100	69,3	61,1	46,1	62	29,3	53,6	55,7	2,9	37	62,8	22	14,7	64,1	41,9	44,7	40,4
Denmark	3	5	85,7	82,5	80,4	62,7	44,9	100	91,4	100	88,6	95,5	67,4	80,6	39,5	85,3	47,5	89,2	85,2	4,3	100	97,1	83,3	38,8	80,6	65,7	95,7	21
Finland	8	9	82,8	80,4	80,8	61,9	46,6	68,5	54,6	100	100	100	81,6	93,8	30	82,3	64,7	90	77	2,9	70,8	86	72,2	23,9	88,2	78,1	81,3	41,3
France	17	17	68,6	67,6	57	53,6	43	44,3	35	100	87,9	100	73,1	69,6	37,4	77,7	23,8	70,3	68,8	13,5	28,2	75,6	28,9	40,6	65,6	63,7	53,8	39,8
Germany	16	16	70,5	69,6	51,3	44,9	46,3	51,2	46	97	78,6	100	61,6	86,8	30,8	67,8	38,6	87,9	76	21	34,2	79,1	32,9	39,7	70,2	50,2	61	37
Greece	37	37	47,4	47	35,1	26	10,9	31,8	15,5	97,1	68,6	93,2	26,9	49,2	12,5	68,7	35,2	43,7	61,5	2,5	31,2	73,3	21	14,1	100	54,8	38,2	36
Hong Kong	14	15	72,7	70,2	50,1	55,6	64,7	39,8	43,3	100	n.a.	90,9	97,2	76,7	42	54,3	48,2	82,5	35,8	3,5	63,7	95,9	54,9	26,3	74,3	50,9	41,4	41,4
Hungary	33	35	51,3	48,5	34,7	39,7	30	17,6	8,8	100	80,5	100	51,6	47	36,6	70,9	22,1	58,6	82,8	1,6	22,3	69,2	14,4	10,7	48,5	43,4	35,4	54,6
India	49	49	39,6	38,8	54,8	59,1	13	2,4	0,3	96,2	81,2	90,9	58,1	74,6	0,5	27,2	0,9	57,8	19	14,9	1,5	47,1	0,6	12,5	27,4	18,3	2,6	12,6
Indonesia	50	50	35	33,5	25,7	25	7,9	4,6	1	100	86,2	100	64,7	71,6	0,3	23,6	4,4	72,5	31,4	3,1	1,6	45,3	0	0	36,4	20,5	2,6	26,4
Iran	47	48	42,2	39,2	50,2	51,9	15	n.a.	n.a.	92,1	62,2	81,8	67	52,8	1,6	33,7	5,1	52,1	10,6	7,3	12	51,7	5	15,2	69,6	36,9	8,1	n.a.
Ireland	19	19	66	64,7	28,7	29,6	35,2	25,2	33,7	100	90	100	68,6	87,6	32,6	75,1	60,1	88,2	63	2,4	64,8	80,8	47,6	18,7	77,8	81,1	49,8	36,8
Israel	18	18	67,4	67,3	39,4	52,1	29,6	50,9	34,6	100	n.a.	95,5	73,3	74,9	10,6	66,3	34,6	91,1	49,5	3,2	48,5	77,9	51,5	30,6	63,4	88	100	34,6
Italy	30	30	54,5	53,4	28,6	33	30,8	32,1	22,5	100	74,2	100	63,8	60	19,5	62,9	18	60,5	54,2	15,7	34,9	77,3	29,4	24,6	61,9	33,4	27,8	35,6
Japan	20	20	61,9	61,7	21,2	51,2	51	37,6	28,9	95,4	56,8	100	83,2	70,8	15,7	39	18,9	57	78	17,2	18,4	50,6	14,5	42,9	63,6	89,7	64,3	34,5
Korea	24	23	58	57,4	32,7	64,4	27,8	37,7	25,7	83,4	70,2	100	58	56,3	8,3	37,9	14,8	62,6	61,4	12,4	32,3	56,4	24,1	24,8	94,3	84,7	91,1	25,2
Malaysia	27	28	56,1	54,5	56,5	75,1	39,4	48	22,9	100	100	95,5	78,6	83,7	29,6	59,5	7,5	79,4	16,3	3,6	15,1	55,8	5,8	14	43,7	37,7	28,6	21,6
Mexico	48	47	41,7	41,1	47,2	50,5	19,5	12,7	4,1	100	n.a.	95,5	82,4	48,5	2,1	53	3,8	52,9	19,5	3	3,2	42,4	0,8	11,1	40,2	31,1	3	20,7
Netherlands	10	10	81,6	80,2	59,8	62,7	51,8	58,3	54,3	100	91,7	100	79,3	88	40,4	82,5	47,5	96,7	85,4	9	70,7	97,7	59,4	37,5	85	66,2	60,7	34,7
New Zealand	14	14	72,7	71,5	44,1	64,5	39,7	33,6	21,4	100	99,7	100	89,7	86,5	72	77,3	55,8	76,1	46,4	2,2	59,5	79,1	64,6	18,4	82	67,9	49,1	33,9
Norway	11	11	80,5	77,8	89,9	70,7	58,4	68,8	74,8	100	92,6	100	66,9	85,9	11,6	80,8	58,9	81	61,8	3,1	78,2	87,2	63	28,1	82	75,3	78,5	32,2
Poland	32	31	52,6	52,2	48,4	43,9	23,8	33,3	17,2	100	90	100	81,9	58,3	15,1	42,3	17,3	60,4	32,3	6,4	22,8	58,1	7,3	14,1	67,8	53,4	30,6	49,1
Portugal	25	25	57,6	56,8	39,4	42,6	29,3	55,3	31	100	88,6	100	60,9	71,7	23,5	71,9	33,9	64,5	41,5	3,6	47,2	66,9	26,7	18,7	63,9	43,1	52	33,7
Romania	44	45	43	41,7	32,9	42,8	28,9	5,2	2,4	100	100	95,5	76	45,2	17,7	36,6	10,2	54	32,1	2,3	15,9	50,6	2,7	5,9	48,2	29,6	10,8	45,8
Russia	35	35	49,1	48,5	37,3	42,5	22,5	9,8	4,6	100	100	100	70,2	60,1	15	36,2	8,4	43,9	20,1	8,8	8,3	47,7	2,9	21,7	81,9	97,9	34,6	47,7
Saudi Arabia	22	22	59,3	59,3	100	77,7	53,1	n.a.	n.a.	96,3	81,7	79,5	50,5	69,3	17,1	100	3,9	68,9	29,6	3,1	12,7	76,7	7,8	24,8	69,7	41,2	n.a.	9,4
Serbia	42	41	44,2	43,4	55,8	48,7	17,4	32,9	8,8	100	93,1	90,9	42,3	52,9	16,3	62,1	8,5	52,1	23,7	1,1	20,5	53,5	9,3	7,4	66,5	37,2	25,2	28,7
Singapore	4	7	84,5	81,3	50,1	53,7	100	63,4	100	100	74,1	95,5	82	94	100	87,7	36,7	91,7	38,6	2,8	66,5	94,8	41,4	26,5	84,8	86,5	81,6	30,6
Slovakia	38	33	47,2	49,6	35,8	37	30,3	21,2	11,9	100	91,5	100	64,2	44,8	25,3	57,7	16,8	35,6	64,4	1	24,2	63,4	4,7	2,9	46,6	42,5	33,9	46,4
Slovenia	28	29	55,4	53,6	44,5	38,3	29,9	20,3	12,6	100	85,1	100	63,7	65,3	14,3	71,1	25,1	63,1	53,6	0,7	48,8	67,4	31,4	7,4	78,6	56,1	54,2	35,9
SAR	34	34	49,7	48,7	37,4	49,9	28,9	26,2	6,1	100	n.a.	88,6	86,7	45,3	11,9	68,6	3,7	54,8	36,9	3,7	8,6	69,8	5,8	18,6	22,4	12,4	6	100
Spain	23	24	58,6	57,3	41,6	45,9	33,5	32	21,6	100	86,9	100	69,9	59,5	11,9	61,6	30,7	57	46,2	12,7	37	65,7	29,9	22	88,9	64,4	34,8	39,7
Sweden	5	4	84,3	82,9	71,2	59,7	64,6	83,2	73,7	100	89,7	100	75,2	76,9	24,8	86,8	59,6	83,1	86,2	6,3	83,5	89,5	82,5	38,8	67	74,7	92	24,4
Switzerland	2	2	90,1	88,6	64,9	51,7	75,4	88	97,6	99,4	71	100	69,5	100	65,2	91,3	79,7	100	76,9	5,8	91,7	100	100	44,2	59,6	75,6	63,7	30,4
Taiwan	21	21	60,5	60,5	33,5	51,8	32,8	29,3	26,2	100	72	93,2	86,9	72,3	16,2	45,4	44,3	80	38,3	5,1	29,1	55,2	20,3	19,7	84,5	84,5	76,1	25
Thailand	46	46	42,3	41,2	32,1	34,8	13,7	13,7	4,2	100	100	95,5	71,9	60,1	4,8	57,8	10,2	65,5	34,7	2,1	4,3	53,5	1,8	11,3	49,3	28,1	14,7	18,2
Turkey	39	42	46,3	43,3	71,1	70,5	27,9	31,5	14,8	92	88	100	44,9	51,3	5,5	30,6	7,6	57,4	16,6	7,2	11,9	44,2	4,1	11,2	94,7	35,9	16,8	23,2
Ukraine	36	38	47,8	45,1	76,4	63,9	10,8	3,2	0,5	100	n.a.	90,9	60,6	62,4	11,6	41,2	8	45,8	60,4	1,3	4,2	33,1	0	0	83,4	84,4	12	58,3
UK	6	3	83,6	84,5	28,2	64,7	63,1	38,8	29,7	100	89,5	100	89,5	75,5	65,8	72,1	63,7	82,1	68,9	31,1	63,1	86	58,1	73,7	60	79,1	53,1	34,4
USA	1	1	100	100	42,6	91,2	80,1	35,7	37,7	100	98,2	100	100	90,8	19	45	100	92,3	58,4	100	41,2	78,5	43,4	100	88,2	81,9	51,6	48,7

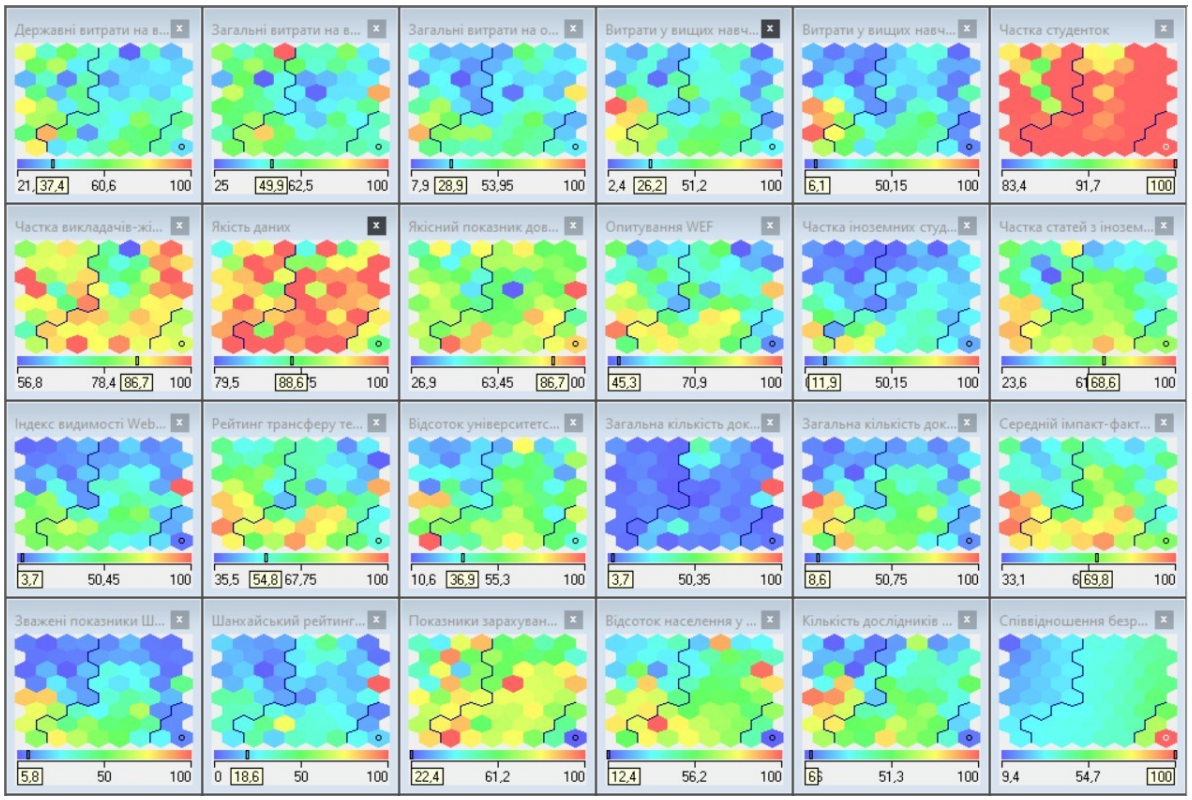

Figure 2: Kohonen topological maps for all indicators of university competitiveness assessment.

when clustering countries, but will serve as a reference when analyzing clusters).

To carry out clustering based on Kohonen maps, it is necessary to avoid gaps in the data. Since there are only 50 countries in this database, moreover, the scores for each individual indicator for different countries are quite close to each other, so we will not divide countries into groups and replace the blanks with the corresponding average values for all countries. This will not lead to distortions of the clustering results, since the percentage of gaps in this database is very small.

4 MODELING THE UNIVERSITY COMPETITIVENESS

The construction of Kohonen self-organizing maps in our study was carried out using the analytical platform Deductor Studio Academic. In the process of constructing a map, the task of finding its optimal dimension (number of neurons) arises, which is implemented experimentally on the basis of statistical data. The dimension of the self-organizing map was chosen from various options according to the mean weighted quantization error criterion, which reflects the average distance between the data vector given to the map inputs and neurons' parameters.

A hexagonal lattice of neurons with dimensions of 8 by 8 was determined as the most adequate structure of a self-organizing map for this task according to a given set of indicators (table 1). Self-organization occurs over 1500 learning epochs.The map parameters are initialized with small random variables. Gaussian (4) was chosen as a function of the neighborhood of neurons. Since all indicators for assessing the competitiveness of universities are already presented on an identical scale from 0 to 100, none of them will have a decisive influence on the clustering process. Therefore, it was decided to build Kohonen maps on the original data without processing them. As a result of the process of self-organization, the countries from the table 1 were distributed among three clusters, which can be seen in figure 2.

As can be seen from the topological maps for all indicators in figure 2, for the vast majority of them there is no clear demarcation of their levels between clusters. That is, their low, medium and high values are evenly distributed throughout the map, which, together with the low levels of significance of many indicators (figure 3), does not contribute to the quality of the countries segmentation process.

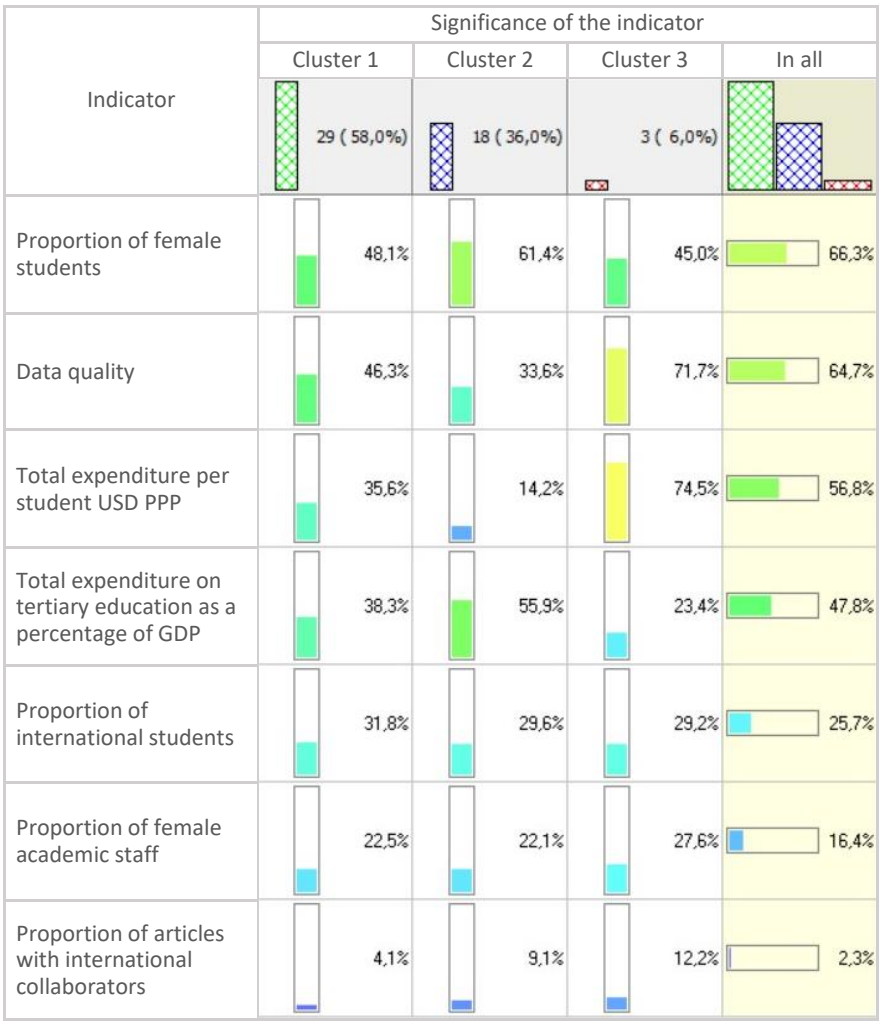

Figure 3: Levels of significance of a number of indicators for evaluating the competitiveness of universities.

Given the low significance of a large number of indicators selected for the study, a series of experiments was conducted on the construction of Kohonen maps on different sets of input variables, when various combinations of the least influential factors were alternately removed. However, each time the same low quality of the distribution of countries by the levels of university competitiveness evaluation indicators remained. For example, for all clustering options, Bulgaria, South Africa, Poland, the Russian Federation, Romania, Slovakia, Hungary, and Croatia were located next to Ukraine on Kohonen map, but the United States was also a neighbor in this cluster. Of course, such segmentation of countries cannot be considered acceptable.

Therefore, it was decided to apply z-score standardization to process the initial values of the variables. As a result of forming a map on the full set of standardized explanatory variables, 5 clusters were obtained (figure 4).

Figure 4 shows that the levels of indicators change when crossing from cluster to cluster, which indicates a successful delimitation of countries based on a given set of explanatory variables. Ukraine got to the upper right corner of the Kohonen map next to Argentina, Bulgaria, Poland, the Russian Federation, Serbia, Turkey, Croatia, and Chile. Somewhat lower in the same cluster were Brazil, India, Indonesia, Iran, China, Malaysia, Mexico, South Africa, Romania, Slovakia, and Thailand.

Austria, Denmark, the Netherlands, Norway, Singapore, Finland, Switzerland, Sweden are located in the opposite corner of the map from Ukraine (bottom left). The United States and Great Britain were located in the upper left corner of the map. They are surrounded by Australia, Hong Kong, Israel, Canada,

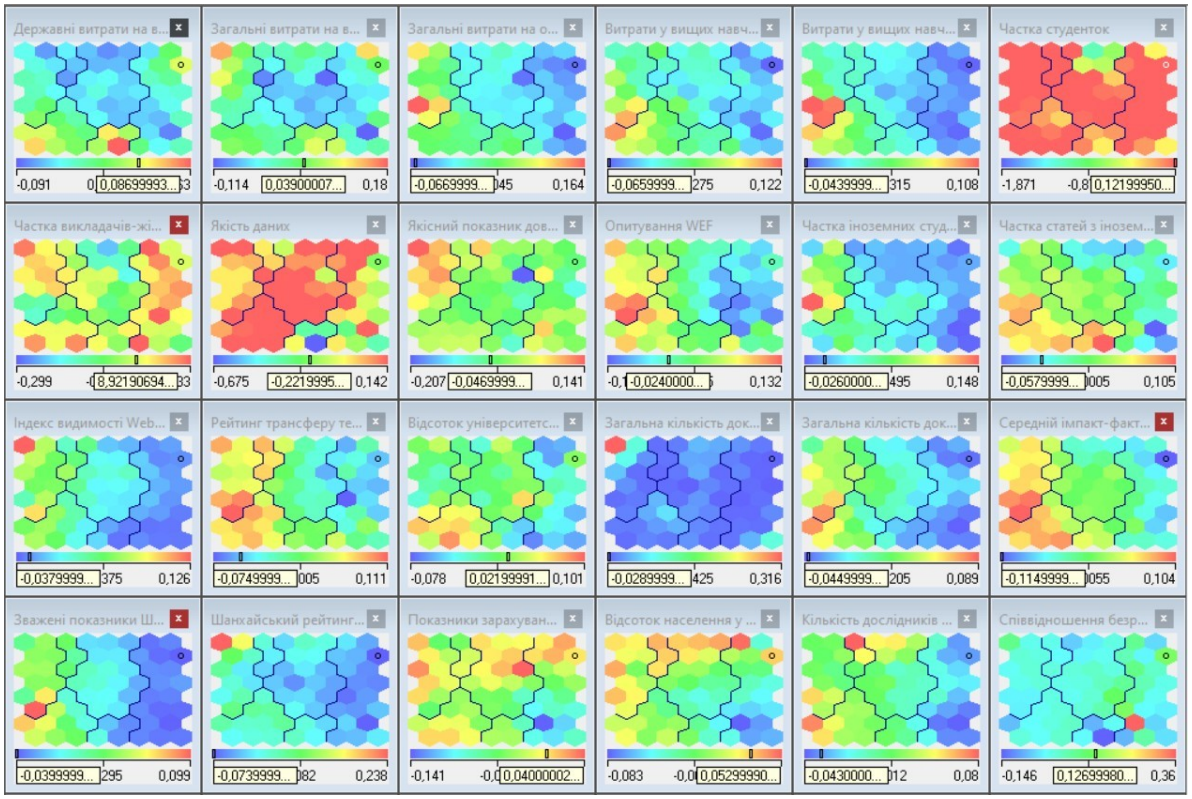

Figure 4: Kohonen topological maps according to the normalized indicators of university competitiveness assessment.

and Taiwan.

It should be noted that since, in accordance with the given task, polar objects are located on the Kohonen map in opposite corners, this self-organization of countries indicates that the competitiveness of Ukrainian universities is currently quite far from the competitiveness of universities in developed countries.

The analysis of the characteristics of the universities of the countries of the most developed cluster makes it possible to determine the priority areas of development and tasks that must be solved in order to increase the international competitiveness of Ukrainian universities.

Research and generalization of traditional, entrepreneurial, innovative and creative models of universities, their selection depending on objective endogenous and exogenous conditions and imperatives of the development of Ukrainian higher education made it possible to substantiate the most adaptive competitive model of the university, which is shown in figure 5.

Critically important in the proposed model is the development of strategic partnership in the triangle "science – business – education", public-private partnership and consolidated social responsibility.

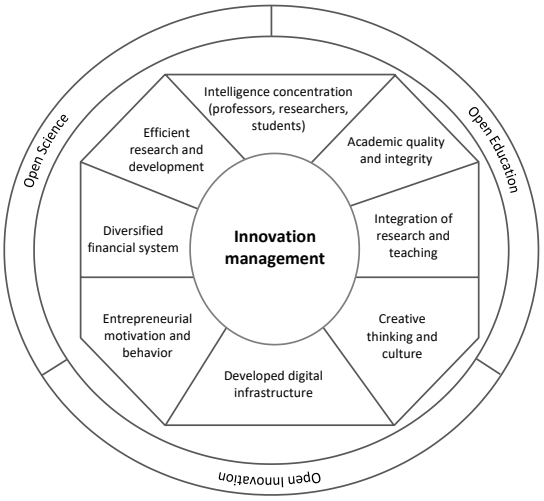

Figure 5: Competitive model of the university.

5 CONCLUSIONS

The global transformation of university education raises new challenges for state authorities in the field of education and university administrations to ensure their competitiveness in the international market of educational services. In the context of increasing the

efficiency of the university management process in modern globalization conditions, the tasks of assessing its international competitiveness arise.

In today's world, the ways of innovative behavior of corporations, universities and other organizations must take into account the need to act in conditions of political, market and social turbulence, which necessitates the constant generation of non-standard ideas, strategic concepts, models and behaviors.

This research is aimed at developing a new methodological approach to the study of such a poorly formalized indicator as the competitiveness of universities. Since competitiveness does not have generally accepted evaluation indicator, units or measurement scales, etc., it was decided to apply the clustering approach for searching of hidden regularities in the set of explanatory variables.

Accordingly, the article carried out a thorough analysis of existing approaches to evaluating the competitiveness of universities and identified unresolved problems in this sphere. In addition, various methods of clustering, their advantages and features were analyzed, and the most appropriate method for solving the problem was chosen.

The use of the Kohonen self-organizing map toolkit was justified, which, in addition to forming homogeneous groups of researched objects, provide a convenient tool for visual analysis of clustering results.

In addition, the methodology of self-organizing maps provides an analytical tool for searching the indicators which are lagging the most, so that management actions can be focused on increasing the competitiveness of Ukrainian universities in the global market of educational services.

As a result of the conducted research, a competitive model of the university was formed during the analysis of the competitive advantages of the universities of the countries included in the most competitive cluster.

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