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Models of the Impact of Socio-Economic Shocks on Higher Education Development

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Abstract: This article is devoted to the analysis of the impact of socio-economic shocks on the dynamics of higher education development. It is substantiated that, on the one hand, higher education influences the development of society and the economy, on the other hand, the development trends of a country provide both opportunities and limitations for its development. An algorithmic model for studying the impact of social and economic shocks on the development of the higher education system (HES) has been developed. To diagnose the relationship between higher education and the socio-economic development of Ukraine and Slovakia, the following indicators were used: GDP per capita, the Human Development Index, school enrollment, tertiary, and net migration. The presence of nonlinear trends in the change in indicators has been shown and portraits of the socio-economic development of the countries have been constructed. To assess the impact of socio-economic shocks on the HES, the time-series decomposition method and cross-spectral analysis were used. The time-series decomposition allowed us to identify cyclical components of indicators, based on applying cross-spectral analysis, and the most significant local harmonics and the lag of their influence on the occurrence of shocks in the HES were determined. The use of the developed models allows us to predict periods of shock points in the HES depending on shocks in the tendencies of GDP per capita and net migration.

Keywords: higher education; shock points; cross-spectral analysis; trend; model; impact; harmonic

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1. Introduction

Education is a key trigger for the development of civilization, which is why significant transformations—caused by main trends in the development of the world in the 21st century—are the focus of research by various international organizations, national governments, and individual researchers. As UNESCO experts note, education is, on the one hand, a right that expands human rights, on the other hand, it is a powerful tool for reducing inequality in society, allowing one to fully participate in the life of society, break out of socially lower strata, and be fully realized in life.

To make this possible, a system of legal documents and instruments has been developed in the international arena. Thus, the human right to education is enshrined in the Declaration of Human Rights (1948), Convention against Discrimination in Education (UNESDOC 1960), the Global Convention on the Recognition of Qualifications concerning Higher Education (UNESDOC 2019), regional conventions (UNESDOC 2023). A significant contribution to the understanding of new tasks, development goals, and modernization of education in the 21st century was made by the World Education Forum, "Education 2030: Incheon Declaration and Framework for Action for the implementation of Sustainable Development Goal 4: Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all" (UNESDOC 2015).

That is, higher education faces ambitious goals of further transformation in the direction of strengthening equity, inclusion, and gender equality; enhancing quality in education based on innovative approaches; promoting lifelong learning; and providing HE in emergencies of natural disasters and military conflicts. These directions for restructuring the higher education system are especially relevant for Ukraine, which is striving to fully integrate into the European scientific and educational community.

The main task of modern higher education in Ukraine is to ensure the appropriate quality of training of specialists, which is based on modern achievements of world science and ethical principles and educates a developed personality. However, any education should be aimed, first of all, at ensuring the social and economic needs of the state, its development, and its integration into European space. The Ministry of Education and Science of Ukraine is optimizing the network of higher education institutions in Ukraine. In addition, individual educational trajectories are being introduced into the activities of universities; a transition is being made to hybrid forms of education; a grant system for admission to universities is being introduced; and conditions are being created for the digitalization of educational processes and the development of innovatively active entrepreneurial universities.

The legal basis for these transformations comprises the laws of Ukraine "On Education" (2017); "On Higher Education" (2014); "On Scientific and Scientific-Technical Activities" (2016); "On Amendments to the Law of Ukraine "On Higher Education" Regarding Ensuring the Right to Obtain Higher Education for Persons Whose Place of Residence is the Temporarily Occupied Territory of Ukraine" (2017); Resolutions of Cabinet Of Ministers Of Ukraine "On the approval of the National Framework of Qualifications" (2011); "On the approval of the Regulation on educational and qualification levels (degree education)" (2013); "On the approval of the Procedure for implementing the right to academic mobility" (2015); "On approval of the list of fields of knowledge and specialties for which higher education applicants are trained" (2015); "About documents on higher education (degree)" (2020) (Official Website of the Parliament of Ukraine n.d.).

Although higher education has a significant impact on the development of national socio-economic systems, the economy and society also have a significant impact on the development of the country's higher education system. The well-being of the population, trends in demographic processes, the level of economic development of the country, and the intensity of migration processes are the main factors that determine the development of higher education. Although these factors are representative of the global higher education system, each country has specific characteristics, which determine the relevance of these studies.

2. The Literature Review

A large number of studies, both at the level of international organizations and individual scientists and practitioners, are devoted to the study of the role and place of higher education and universities in the socio-economic development of civilization and individual countries. The higher education systems of countries and their key components, universities, are in constant development and interaction both with each other and with the main stakeholders—the state, representatives of the labor market, public organizations, potential applicants, and students.

An analysis of how effective education policy is developed in each country allows us to identify its most important components, namely: access and participation, equity, socio-economic status, education attainment, student and adult skills, economic and social outcomes, social and health outcomes, earnings, public returns, education for innovation, career guidance, and student mobility (OECD 2023, 2022; Website OECD 2024).

The progress of countries in achieving sustainable development goals (SDG) through the changing role of higher education, a new understanding of the phenomenon of higher education in the 21st century, and its development trends are reflected in the following: the UN's official annual report "The Sustainable Development Goals Report" (United

Nations 2022, 2023); the European Commission's annual report on EU education and training systems "Education and training monitor" (European Commission, Directorate-General for Education, Youth, Sport and Culture 2022, 2023); Educause's annual report on advancing higher education through the use of IT "EDUCAUSE Horizon Report" (Pelletier et al. 2022, 2024; Reinitz et al. 2022). Thus, within the framework of the 78th session of the UN General Assembly (UNGA78, New York 2023), the central event was the SDG Summit. World leaders and communities took stock of progress toward achieving the Sustainable Development Goals by 2030 (SDG Summit 2023). Within the framework of Sustainable Development Goal 4—ensure inclusive and equitable quality education and promote lifelong learning opportunities for all—it was emphasized that the low level of digital skills—skills in working with information and communication technologies—is the main obstacle to the widespread use of the Internet in education, including higher education. In addition, the problem of teachers' readiness for significant changes in the forms, methods, and tools of higher education was addressed. The key task, in this regard, is the development and adaptation of teachers' qualification skills to the innovations of scientific and technological progress of the 21st century (United Nations 2022, 2023; Website International Association of Universities n.d.).

Analysis of progress toward sustainable development of civilization requires the development of an effective system for monitoring trends in the transformation of higher education. Today, numerous platforms have been created that provide databases and reports of higher education indicators (Department of Economic and Social Affairs of United Nations n.d.; Migration Data Portal n.d.; The UNESCO Institute for Statistics n.d.; OECD Data n.d.; Website of Eurostat n.d.; Website Statista n.d.; European Commission, European Education and Culture Executive Agency 2022a, 2022b, 2024; European Commission's Directorate-General for Education, Youth, Sport and Culture 2023; European Education and Culture Executive Agency, Eurydice 2023a, 2023b, 2024; Website Education Counts n.d.; and others). According to the Incheon Declaration (Education 2030: Incheon Declaration), all indicators are divided into four levels: global indicators (comparable indicators for all countries to monitor progress in higher education and related tasks); thematic indicators (for a comprehensive assessment of countries' achievement of education tasks); regional indicators (to take into account the progress of education within the regional context, political priorities, and concepts); and national indicators (to take into account the national context, determining the relationship of higher education with economic and social trends).

Higher education is one of the key subsystems of the socio-economic development of any country. That is why a large number of studies are devoted to the assessment and analysis of the impact of higher education on socio-economic development. As in the case of Ukraine, the analysis of the impact of higher education on the processes of post-war restoration of a country's socio-economic development is of particular interest.

The development of higher education is aimed at identifying ways to adapt it to the demands of the labor market and creating a qualitatively new higher education capable of taking a worthy place in the market economy and satisfying the needs of each individual in obtaining knowledge and social experience. The authors (Volchik et al. 2018; Chered-nichenko and Gustchina 2016; Mirgorodskaya et al. 2023) prove that higher education as an open complex subsystem is determined by a set of subjective and objective factors and, in turn, has a significant impact on the state of the social system as a whole. The authors (Chetyrbock 2023; Garashchuk and Kutsenko 2024; Fatima et al. 2020) also emphasize that there is a direct dependence of the practice-oriented issues of modernization of higher education on many factors, including the current socio-economic stage of transformation of society. Thus, higher education plays a key role, that is, it contributes to the development of a society based on knowledge. It is the higher education system that provides graduates with innovative skills that help transform society in the future in accordance with the trends of scientific and technological structures through high-quality education, scientific and technical research, grants, and innovations.

All this is happening against the backdrop of a global trend of reducing state funding for higher education. On the one hand, this is a risk factor that negatively affects the financial activities of universities and the state of their material and technical base; on the other, it is an opportunity to give universities more autonomy, to turn a traditional university into an innovative and active organization of an entrepreneurial type. The latter is a trend in the transformation of the world's higher education system.

The limited resources in a country do not always allow the state to provide adequate financial support, which contributes to the development of the higher education system. Today, education is financed not only by budget funds, including the resources of the relevant national project, but also by private financial resources. The studies (Charles and Samon 2023; Ashirbekova and Nurmukhanova 2022; Panigrahi 2023) reflect on the reasons for the change in the fund allocation policy in the education system, consider the existing effective university funding strategies as well as the methods of education financing and their consequences. There are several university funding strategies, including public funding, public–private partnerships, charitable donations, user fees, crowdfunding, bond financing, and attracting existing assets. Public funding (Hrabchuk et al. 2022; Andronic 2023) is a common strategy in developed countries, which involves direct funding of the digital infrastructure and resources of universities. Public–private partnerships (Sheriffdeen et al. 2024) can effectively finance the digital transformation of the higher education system by attracting the resources and expertise of both the public and private sectors. Philanthropic giving plays an important role as individuals, foundations, and corporations are interested in supporting education and the development of digital infrastructure and resources.

An analysis of public funding for different levels of education has led to the conclusion that higher education requires higher levels of funding. Thus, according to OECD experts, the average expenditure per student is about USD 10,700 at the primary level, USD 11,900 at the secondary level, and USD 18,100 at the tertiary level (Website OECD 2024). This reflects the fact that higher education requires teachers to be more highly qualified, to constantly update their skills and pedagogical skills, and to work with students in different ways. All this implies higher wages. Thus, the modern development of higher education financing is experiencing changes due to new challenges related to the strengthening of the digitalization process; the impact of force-margin circumstances on the development of higher education, such as pandemics and military conflicts; changes in the remuneration system for scientists and faculty; the use of grant funding; and the strengthening of the role of universities in regional and national policies. Another challenge of the 21st century that the higher education system faces is globalization processes and the associated population migration processes. Much attention is paid today to the study of the relationship and mutual influence of the educational and socio-demographic systems of a country by both government organizations and scientists. This is due to the fact that intellectual capital is one of the most important determinants of long-term economic development of a country. The relationship between higher education and migration processes in society was studied in (Rayevnyeva et al. 2023a, 2023b); the results showed that the Russian–Ukrainian military conflict caused a significant outflow of Ukrainians with their families to Europe. This led to a decrease in the number of applicants to universities and a decrease in the economically active population of the country. In these conditions, universities faced the risk of disrupting their financial stability and reducing the attractiveness of higher education in broad sections of the population.

The work (Kalmukhanbetova and Shnarbekova 2022) examined migration trends around the world as well as migration trends in higher education institutions and also determined that educational migration largely determines the dynamics and nature of a country's socio-economic development. The authors (Mahato et al. 2022; Chowdhury 2019; Cheng et al. 2023; Stojanovski et al. 2023), in their work, examined the relationship between migration management and higher education and also identified numerous and multidimensional factors influencing migration processes in the development of educational and socio-economic systems of a country in modern conditions. At all times, the reasons for

migration were military conflicts, political instability, lack of economic prospects, the desire to integrate into the EU, and the opportunity to continue education from high school to university level. Thus, the increase in different types of migration are signs of globalization, and the share of migrants in the permanent population of countries reflects the degree of involvement in globalization processes.

Understanding the new role of higher education in society necessitates continuous monitoring of educational processes and modeling of key indicators. Analysis and evaluation of processes and components of the educational system allow its optimization based on the analysis of retrospective trends and the use of a wide range of economic and mathematical methods and models for determining promising opportunities. Thus, in the papers (Larchenko 2023; Prus 2023), arguments are presented confirming the need to use mathematical modeling methods as an integral part of effective system management. The authors emphasize that the progress of computing technology has had and continues to have a huge impact on the development and application of economic and mathematical methods in higher education. Thanks to computer technology, the risk of errors in solving problems and the time spent on their solution are significantly reduced. Mathematical methods play an important role in the analysis of educational processes since they can provide accurate calculations and full consideration of the influence of factors using short-term forecasting methods and effective management decisions.

Economic and mathematical modeling is widely used to approximate and forecast various aspects of higher education. Thus, the authors (Bredyuk and Joshi 2017) modeled the functioning of the higher education system and the demand for its services in Ukraine based on a system of simultaneous equations and linear regression models. To analyze the influence of the population segment with higher education on economic growth (GDP) and the poverty line in 38 OECD countries, authors (Li et al. 2024) used an OLS regression model and the panel quantile model. As noted by researchers (Agasisti and Petrenko 2024), the most common methods used in individual publications over the past 20 years are descriptive statistics methods and regression models in various forms, such as pooled regression, privacy-preserving machine learning (PPML), and covariance or multivariate probit regression.

As the study showed, it is advisable to use the apparatus of vector autoregressive models (Shapor 2021; Pettenuzzo and Timmermann 2017) to assess interstate interdependencies, assess the effectiveness of any reforms in the country, and highlight their impact on economic development. In modern studies (Korobilis 2019; Canova and Ciccarelli 2013), VAR models are used to assess the impact of socio-economic factors on the higher education system. Combinations of VAR models ensure the achievement of advantages in predictive efficiency and take into account time-varying parameters and the stochastic volatility of educational processes.

The conducted analysis of modern trends in the development of higher education and the tasks facing it allowed us to formulate the goal and hypotheses of the study.

This article aims to analyze the impact of shocks in the social and economic development of a country on the development trend of higher education based on the use of the time-series decomposition method and cross-spectral analysis. To achieve the objective of this study, the following hypotheses were formed.

Hypothesis 1. *The higher education system is in constant interaction with the economic, social, and demographic systems of the country, which determines their mutual influence.*

Hypothesis 2. *Crisis changes in the economic, social, and demographic development of a country cause risks in the functioning of its higher education system, which determines the need to monitor changes and adapt to them.*

Hypothesis 3. *To assess and forecast the impact of short-term/long-term shock effects on the higher education system (HES), as well as their lag delay, it is advisable to use the methods of time-series decomposition and cross-spectral analysis.*

This study's structure includes the following Sections: Introduction, The Literature Review, Materials and Methods, Results, Discussion, Conclusions.

3. Materials and Methods

To determine the impact of social and economic shocks on the development of higher education, the algorithmic model presented in Figure 1 is proposed.

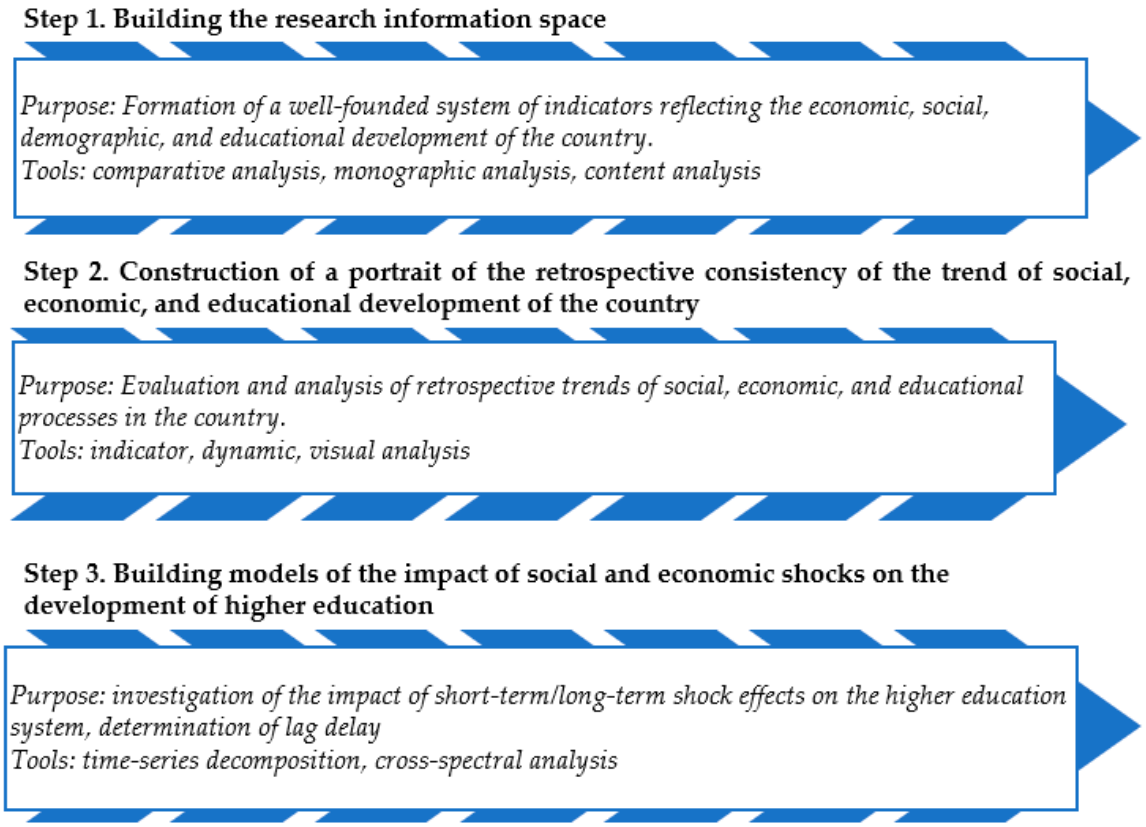


Figure 1. An algorithmic model for studying the impact of social and economic shocks on a country's educational system.

This model reflects the tasks that are solved to achieve the research goal.

To assess and analyze the standard of living of the population, this work proposes to use the Human Development Index (HDI). The HDI was developed in 1990 and is published within the framework of the UN Development Program in annual reports on human development (Website (UNDP) n.d.).

The HDI is an integral indicator, and includes three groups of indicators, which have the following cortege form:

$$HDI = \{LE: ILR; ISL\} \quad (1)$$

where LE—life expectancy; ILR—literacy rate of the country's population; ISL—standard of living measured by GNI per capita at purchasing power parity (PPP) in US dollars.

The peculiarity of the HDI is that the main place is occupied not by the ability of the population to productive work, that is, its economic value, but by the social aspect of development, which is achieved on the basis of increasing life expectancy, increasing income and raising the level of education.

To determine short-term or long-term shocks in the social and economic development of a country and their impact on the development of a higher education system, the use of time-series decomposition methods and cross-spectral analysis are proposed.

The nature of the short-term/long-term shocks is the wave nature that describes the cyclic component in the time series. Therefore, we are making a time-series decomposition for the detection of the cyclic components. The preliminary step is to determine whether there are components in the time series (Figure 2). For this, Fisher's criterion and the Foster–Stewart method are proposed.

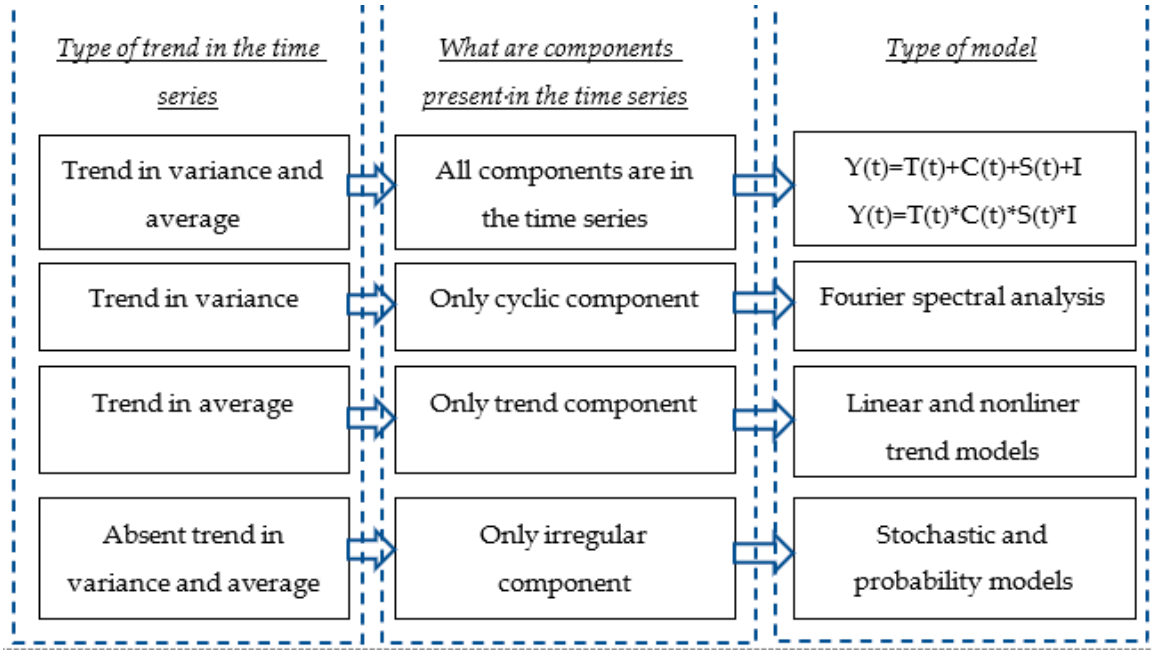


Figure 2. The determination of the components of the time series.

Fisher's F-test method is used to determine the presence of a trend in the variance. For this, the initial series must be divided into two aggregates that may intersect.

After that, the variances of the obtained series (S_1^2 and S_2^2) and the value of Fisher's F-criterion are found according to the following formula:

$$F = \frac{S_1^2}{S_2^2} \text{ if } S_1^2 > S_2^2 \text{ or } F = \frac{S_2^2}{S_1^2} \text{ if } S_1^2 < S_2^2 \quad (2)$$

If $F < F_\alpha(m_1, m_2)$, then the hypothesis about the presence of a trend in the time series is not confirmed and it can be assumed that there is no such trend. In the other case, when the trend in the variance exists, there is also a trend in the time series. Here m_1, m_2—the number of elements in the first and second row.

Foster–Stewart method. This method has great possibilities and gives more reliable results than the previous one. In addition to establishing the presence of a trend in the series itself (the trend in the average), it makes it possible to establish the existence of a trend in the dispersion of the time series: if there is no trend in the dispersion, then the spread of the levels of the series is constant; if the variance increases, then the series "shakes".

Decomposition of the time series helps us to determine the trend and cyclic components. Cyclic components are investigated with the help of the Fourier transformation (spectral Fourier analysis). In our paper, we need to use the cross-spectral (spectrum) analysis to study of the impact a one-time series (independent series that has a shock in dynamics) on the other time series (an indicator of the development of the HES).

Cross-spectrum analysis allows you to analyze two time series at the same time. Scientists (Bloomfield 2000; Box and Jenkins 1976; Brillinger 1975; Brigham 1974; Elliott and Rao 1982; Priestley 1981; Shumway and Stoffer 2017; Wei 1989) consider cross-spectrum analysis to be more advanced than single-spectrum (Fourier) analysis.

With the help of cross-spectrum analysis, the relationship between two time series is determined as a function of frequency. When conducting a cross-spectral analysis, it is assumed that statistically significant peaks at the same frequency will be present in the studied time series as well as whether these periodicities are related to each other. If such a situation is observed, then it is necessary to determine the phase relationship between them. Conducting a cross-spectral analysis is possible even in the absence of peaks in the power spectrum since coherent modes at certain frequencies may exist in this spectrum of red noise. All this is checked using the coherence spectrum. In cross-spectrum analysis, we used two series as follows:

$$x = \overline{x} + \sum_{k=1}^{\frac{n}{2}-1} \left(A_{xk} \cos\left(\frac{2\pi kt}{T_{kx}}\right) + B_{xk} \sin\left(\frac{2\pi kt}{T_{kx}}\right) + A_{xN/2} \cos\left(\frac{\pi Nt}{T_{kx}}\right) \right) \quad (3)$$

$$y = \overline{y} + \sum_{k=1}^{\frac{n}{2}-1} \left(A_{yk} \cos\left(\frac{2\pi kt}{T_{ky}}\right) + B_{yk} \sin\left(\frac{2\pi kt}{T_{ky}}\right) + A_{yN/2} \cos\left(\frac{\pi Nt}{T_{ky}}\right) \right) \quad (4)$$

where A_{xk}, A_{yk}—cosine coefficients in the Fourier analysis; B_{xk}, B_{yk}—sine coefficients in the Fourier analysis; T_{xk}, T_{yk}—periods of k-harmonics.

When a cross-spectrum study is conducted, it is a set of numbers that can be divided into two parts: real and imaginary. To obtain an estimate of the cross density and quadrature density, the entire complex of numbers must be smoothed. In turn, the cross-amplitude is the square root of the sum of the squares of the cross-density and quad-density values, which can be interpreted as a measure of the covariance between the frequency components of the two series (Shumway and Stoffer 2017).

When conducting a cross-spectral analysis, the following characteristics are calculated:

Squared coherency. This is interpreted as the square of the correlation coefficient, i.e., the coherence value is the quadratic correlation between the cyclic components in two series for the same frequencies and a constant phase difference in their oscillations. Usually, this indicator should be analyzed in combination with, for example, the spectral density.

Gain. The gain value is calculated as the ratio of the cross-amplitude value to the spectral density estimate for one of the two series under investigation. Thus, when analyzing two series, two gain values will be calculated. Conclusions based on the obtained values are interpreted as standard regression coefficients by the method of least squares for the corresponding frequencies.

Phase shift. To determine the delay in the impact of socio-economic shocks on the higher education system, a phase shift is used, which is calculated as the $\tan^{-1}$ ratio of the squared density estimates to the cross-density estimate. Phase shift estimates are said to be measures of the degree to which each frequency component of one time series leads the other.

4. Results

Step 1. Building the information space of the study. In order to achieve the goal of this study and confirm Hypothesis 1, it is necessary to form a system of indicators that would have a significant impact on the development of a country's higher education system. Analysis of the specifics of the activities of universities showed that the success of their development depends on the general economic state of the country, demographics, migration processes and, as a consequence, the income of the population. To confirm Hypothesis 1, a monographic and comparative analysis of literary sources was carried out, various approaches to identifying indicators that are interrelated with higher education indicators were analyzed.

1. Economic development. The authors of (Dimoso 2024; Marto et al. 2022; Appiah 2017; Wen 2023; Munir et al. 2023; Shafiq 2010; and others) argue that when studying the influence of economic factors on education and vice versa, GDP per capita should be used since its growth will reflect the scale of the increase in the general standard of living of society. GDP per capita not only reflects the level of economic development in the country but also serves as an indicator of the level of well-being of the population;
2. Social development. Most authors conclude that one of the significant factors that reflects the level of social development of the population is income or household consumption. The authors proposed to use the Human Development Index since this index reflects measurements of the standard of living, literacy, education, and longevity as the main characteristics of the country's human potential, However, that is impossible to reach without a certain income;
3. Demographic development. Studying demographic trends and factors influencing the higher education system, the authors (Mahato et al. 2022; Chowdhury 2019; Cheng et al. 2023; Stojanovski et al. 2023; Ferreiro-Seoane et al. 2024; Sushchenko et al. 2022) believe that the increase in migration flows negatively affects not only the country's economic development but also the education system. Thus, this article proposes the no-migration indicator to assess its impact on HES.
4. HES development. Researchers (Cao et al. 2024; Kurylo and Karaman 2023; Kremen et al. 2023; Levchuk 2024; Algirdas and Tomas 2023; Batool and Liu 2021) believe that one of the indicators reflecting the effectiveness of the higher education system is the number of incoming/graduating students.

Thus, to assess the socio-economic shocks to HES activity, the following indicators are proposed: GDP per capita, the Human Development Index, school enrollment, and tertiary and net migration.

For calculations, databases of UNESCO, the World Bank, Eurostat, OECD, and the Ukrainian Statistics Service for the period 1990–2023 were used.

Step 2. Construction of a portrait of the retrospective consistency of trends in the social, economic, demographic, and educational development of the country.

Economic development determines the extent of the increase/decrease in the general standard of living of society (Figure 3).

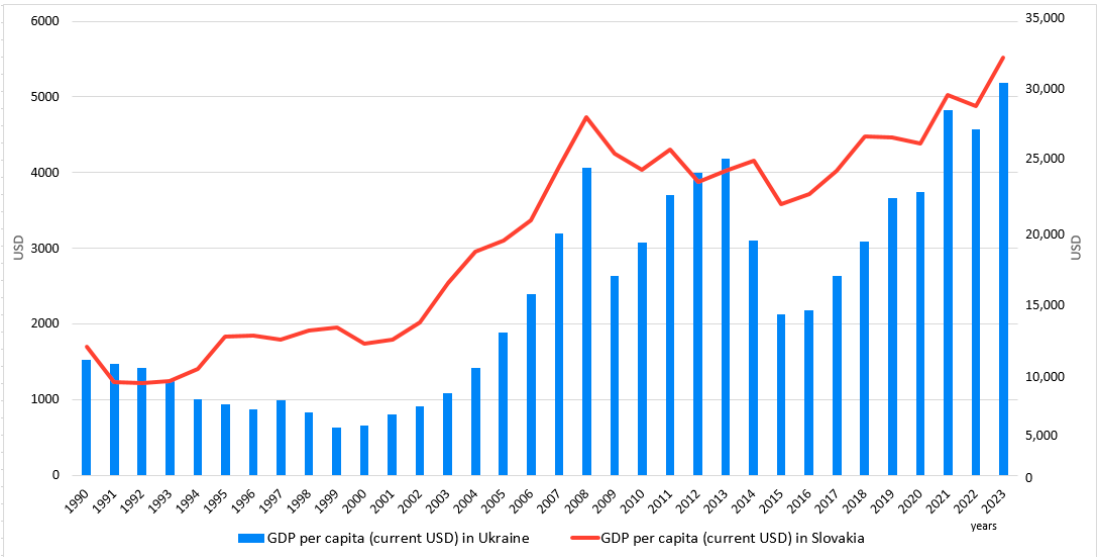


Figure 3. GDP per capita in Ukraine and Slovakia, USD (Website World Bank n.d.).

Analyzing the data presented in Figure 3, we can conclude that the indicator in Ukraine and Slovakia has a nonlinear trend and that there are certain points of local maximums and minimums. In general, the indicator trends reflect the upward vector of a country's

development; however, in Ukraine, the values of GDP per capita are an order of magnitude lower than in Slovakia. This emphasizes the existence of a significant gap in the social and economic development between these countries.

Four characteristic periods can be distinguished for Ukraine:

Years 1990–1999—a period characterizing a low level of economic development of the population;

Years 1999–2008—a period of prosperity and positive dynamics in increasing the standard of living of the population;

Years 2008–2015—a period of recovery of the population's income after the global financial crisis in 2008; however, in 2014, the level of economic development of the population rapidly declined due to Russia's invasion of Ukraine and the annexation of Crimea;

Years 2015–2023—adaptation of the economy to the political and military conflicts taking place in the country as well as the desire to increase economic development.

Slovakia is characterized by three periods of development:

Years 1990–2008—a period characterized by prosperity and positive dynamics of increasing the population's life against the background of high rates of economic growth;

Years 2008–2015—a period of declining economic development rates associated with political and economic instability in the world and the country (2011);

Years 2015–2023—a period of recovery from the crisis associated with the socio-economic development strategy of the new government.

The income of a population and its satisfaction with life have a significant impact on the possibility of access to higher education. An analysis of the dynamics of social development indicators—the Human Development Index and Household income (Appendix A) allowed us to conclude that there is a unidirectional trend in the change in indicators. Since this study makes cross-country comparisons, it is proposed to use the Human Development Index as an integral indicator of social development.

Figure 4 shows the dynamics of the Human Development Index in Ukraine and Slovakia.

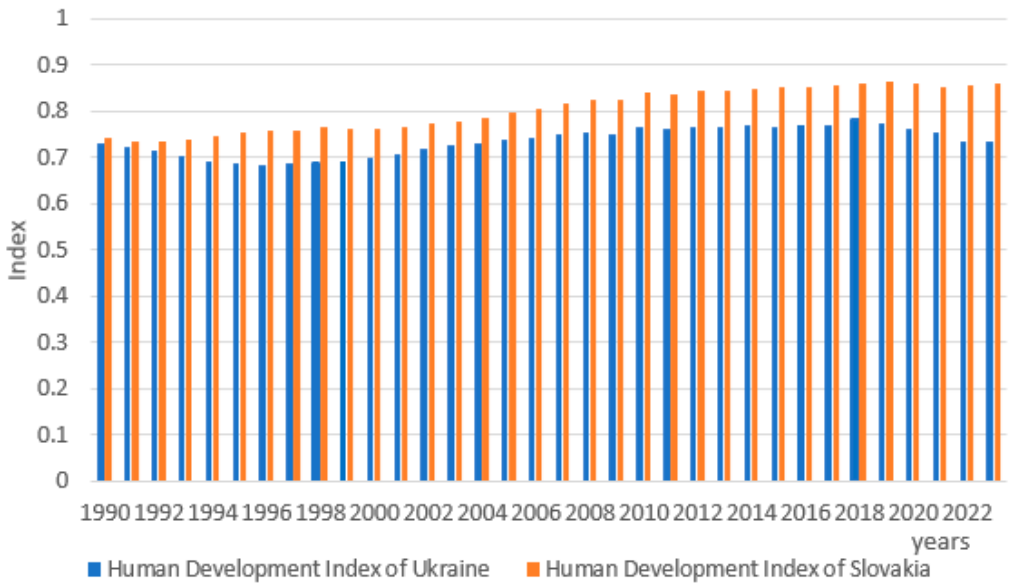
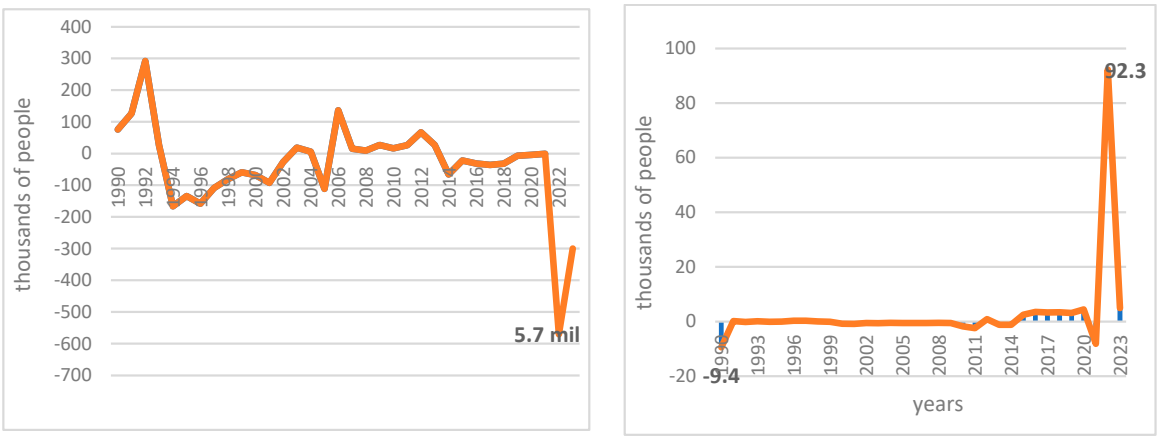


Figure 4. HDI of Ukraine and Slovakia (Website World Data Atlas n.d.; Website World Bank n.d.).

The analysis of the HDI of Slovakia shows a stable trend of change in its values in the range [0.73 ÷ 0.86], which reflects the presence of a high level of real and potential opportunities for human development, a respectable standard of living, and access to knowledge.

Analyzing the dynamics of the HDI of Ukraine (Figure 5a), three periods of development can be distinguished:



(**a**) (**b**)

Figure 5. Dynamics of net migration, thousands of people (Migration Data Portal): (**a**) net migration of Ukraine; (**b**) net migration of Slovakia.

Years 1991–1998—a period characterized by a decline in the social security of the population and a decrease in the level of income of the population, which is associated with the emergence of an independent Ukraine and the establishment of market relations. In 1998, the country experienced its most severe crisis in socio-economic development;

Years 1998–2018—a period characterized by an upward trend in the social development of the country. However, this period has two bifurcation points: 2009—a response to the global crisis of 2007–2008; 2015—a response to the political crisis in Ukraine 2013–2014;

Years 2018 to the present period—a period of deterioration in the well-being of the population due to political and military conflicts and a decrease in the level of employment of the population as well as the number of students in higher education institutions.

One of the demographic trends of the country, the factors of its decline and development, is determined by the migration of the population (Figure 5).

Analyzing the amount of migration of the population of Ukraine for the period from 1990 to 2023 (Figure 5a), we can talk about the unstable dynamics of the development of this indicator, which has a larger number of outflows of the population than inflows.

Among the reasons for the outflow of the population, it is advisable to highlight the following: job search, improvement of housing conditions, increase in the standard of living, change in lifestyle, as well as military conflicts in the country. From February 2022—the beginning of the full-scale invasion of Russia—to 2023, the largest migration outflow of the population has been observed: more than 14 million Ukrainians—a third of the country's population—left their homes. More than 6.5 million of them are scattered around the world as refugees, and about 3.7 million remain displaced persons in Ukraine. This has negative consequences not only for the country's socio-economic development but also for the education system.

An analysis of migration processes in Slovakia (Figure 5b) showed that the period 1992–2011 was characterized by a slight excess of migrants over emigrants; however, since 2012, the net migration indicator shows that Slovakia has become attractive to emigrants. The flow of migrants to Slovakia, including from Ukraine, began to grow and in 2022 their number reached 92.3 thousand people. Such a sharp increase in migrants is due not only to Russia's military aggression against Ukraine but also to the peculiarities of the country's socio-economic development. Thus, since 2015, the country has needed to attract both an additional labor force for economic growth and government-initiated measures to increase labor migration, particularly from non-EU countries.

The development of the higher education system, namely the effectiveness of its activities, determines school enrollment in tertiary higher education institutions (Figure 6). Tertiary school enrollment directly affects the number of qualified employees, labor productivity, and the level of income of the population.

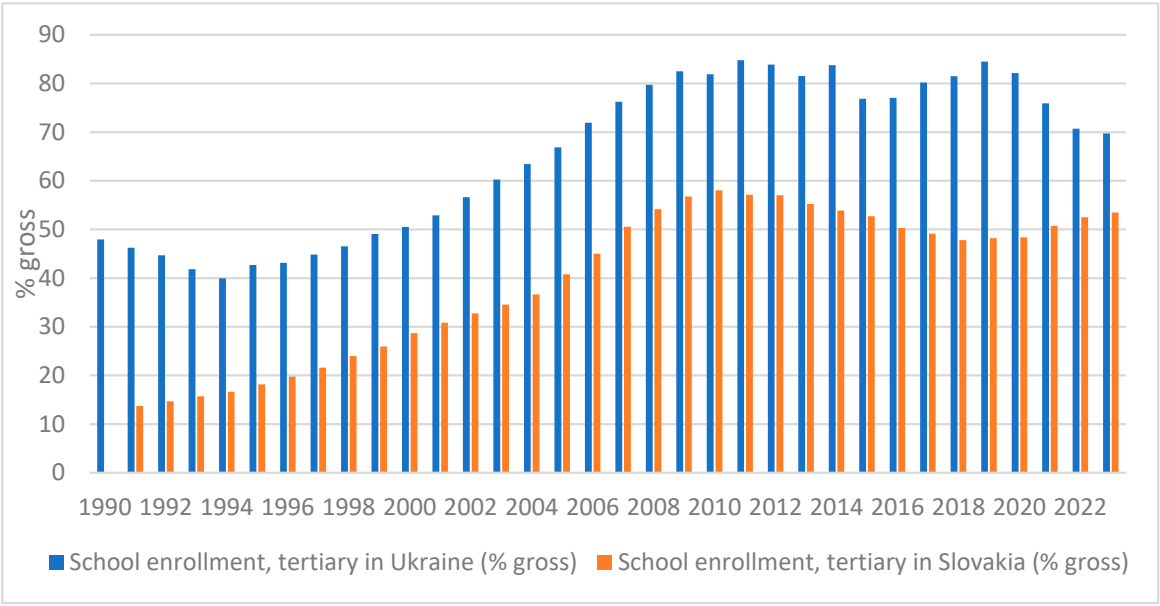


Figure 6. Trends of School enrollment, tertiary in higher education institutions of Ukraine and Slovakia (Website World Bank n.d.; Website World Data Atlas n.d.).

In general, the trends of this indicator for Ukraine and Slovakia are almost the same; however, in Ukraine, the indicator values are 1.5 times higher than in Slovakia. This reflects that the attractiveness of the higher education system in Ukraine is higher than in Slovakia for both national and foreign applicants.

The sharp decline in the birth rate, which was observed in Ukraine in the first years of independence, led to a decrease in the contingent of graduates of secondary educational institutions and, as a consequence, to a decrease in the number of applicants wishing to obtain higher education (Figure 6). Until 1996, the number of applicants to higher education institutions was described by the dynamics of decline, and starting from 1997 to 2013, their number gradually began to increase. The largest number of applicants to higher education institutions was recorded in 2011 but in 2023 their number returned to 2005 levels. A rapid decline in the number of applicants began in 2014—the beginning of military actions in the east of Ukraine and the annexation of Crimea. The economic, political, and military situation in the country affects the activities of higher education institutions at national and international levels, namely, in attracting foreign students to study in domestic higher education institutions.

Analysis of the trend of the school enrollment, tertiary (% gross) indicator for Slovakia allowed us to conclude that the changes are associated with both the internal transformation of the country's higher education system and external factors. Thus, three periods can be distinguished in the dynamics of this indicator: 1991–2010, an increase in the number of applicants due to the transformation of university management structures and the entire higher education system—the orientation of universities being not only on education but also on scientific research—and the expansion of the autonomy of universities; 2011–2019, a decrease in the number of applicants due to demographic factors and an increase in the attractiveness of educational migration for young Slovakians; 2020–2023, an increase in the number of applicants due to external migration processes associated with military actions in Ukraine and the search for people for safe places of residence and study.

Thus, an analysis of the indicators influencing the country's HES was conducted, which showed that all indicators have a nonlinear development pattern. The country's higher education system also has a nonlinear development trend. This confirms Hypothesis 2 about the existence of a relationship between the country's socio-economic development and the higher education system. A comparative analysis of characteristic points in the trends of changes in the analyzed indicators allowed us to conclude that the reaction of

the higher education system to their impact coincides or lags. Therefore, to prove the presence of this interaction between the indicators or lag delays, it is necessary to use special economic and mathematical methods.

Step 3. Building models of the impact of social and economic shocks on the development of higher education.

To achieve the goal of this study to determine the shock impacts of social and economic development of the country on the higher education system, the following is necessary: (1) To prove the presence of cyclical components in the analyzed indicators, determine significant harmonics in them, and construct a general model of the cyclical component. This allows us to substantiate the list of indicators that have a shocking effect on the development trends of the higher education system; (2) to assess the shock effect and determine the lags of its delay on the higher education system. This is necessary for the formation of government decisions and measures to localize or eliminate the negative impacts of the external environment on the HES. To solve Equations (3) and (4) and prove Hypothesis 3, this study proposes to use the time-series decomposition method and cross-spectral analysis.

Stage 1. Decomposition of the time series.

To determine the presence of a trend and a cyclical component in the series of analyzed indicators, this study used the Foster–Stuart criteria (Table 1).

Table 1. Foster–Stuart criteria for the detection of trends in variance and average.

Time Series	Interpretation of Criteria	
	Ukraine	**Slovakia**
GDP per capita	Trend in variance and average	Trend in variance and average
HDI	Trend in variance and average	Trend in variance and average
Net migration	Trend in variance	Trend in variance and average
School enrollment	Trend in variance and average	Trend in variance and average

Source: Authors' calculations.

Table 1 shows that most time series have both trend and cyclical components. Only the time series of the net migration for Ukraine has a cyclic component. Therefore, we can make a time-series decomposition. In this study, we used Statistics 11.0 software. The investigated period was from 1990 to 2023; however, after the invasion of Russia in Ukraine, a lot of Ukrainian people went abroad and, therefore, the Ukrainian indicators during 2022–2023 have anomalous values. Thus, we excluded the years 2022–2023 from our investigation.

The first step in the time-series decomposition is to recognize the type of trend. Analysis of the graphs and growth coefficients show that the linear trend is more adequate for this time series. The coefficients of the trend models are presented in Table 2 (Sims 1980).

Table 2. Trend models of the examined time series.

Time Series	Trend Models	
	Ukraine	**Slovakia**
GDP per capita	$Y(t) = 449.1165 + 106.1255 \times t$	$Y(t) = 5832 + 716.8 \times t$
HDI	$Y(t) = 0.6867 + 0.0029 \times t$	$Y(t) = 0.7222 + 0.0048 \times t$
Net migration	none	$Y(t) = -1712.4435 + 86.7049 \times t$
School enrollment	$Y(t) = 38.2656 + 1.6241 \times t$	$Y(t) = 14.6818 + 1.4473 \times t$

Source: Authors' calculations.

Elimination trends from the time series provide the cyclic and irregular components of the time series. The extreme points of the cyclic components represent the points of shock in this paper. The graphs of the cyclic components are shown in Figures 7 and 8 for Slovakia and Ukraine, respectively.

Stage 2. Single-spectral analysis. This study used spectral analysis to identify shocks in social and economic factors and assess their impact on the HES. This analysis helps us to determine the most powerful harmonics, their amplitude, and periods and the combination of these harmonics will allow us to build a forecasting model for the cyclical component of the time series. Figures 7 and 8 show cyclic components with different periods, frequencies, and amplitudes.

The results of the decomposition of the cyclic components are displayed in Table 3 for Slovakia.

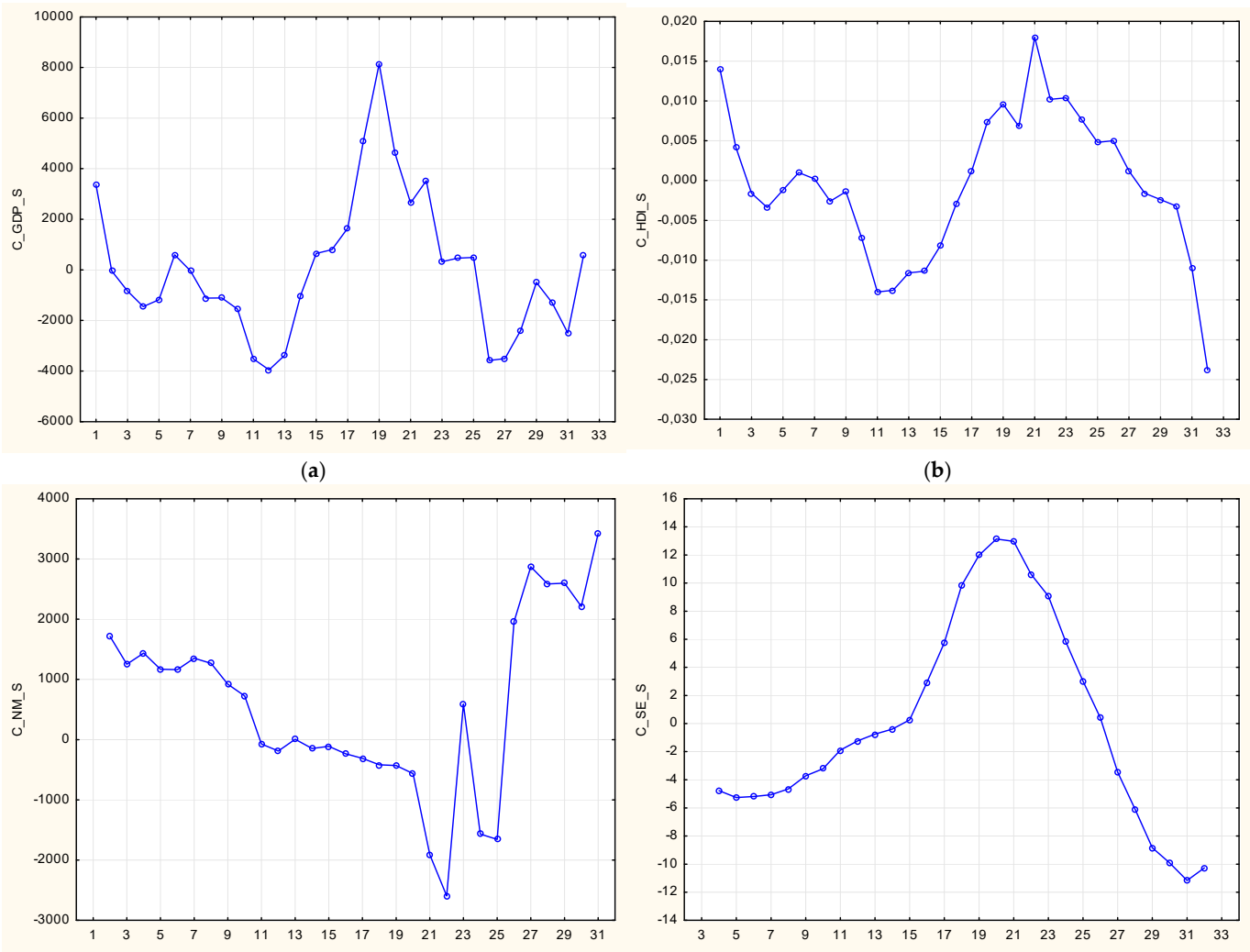


Figure 7. The cyclic components of the time series for Slovakia: (**a**) GDP per capita; (**b**) HDI; (**c**) net migration; (**d**) school enrollment, tertiary (% gross).

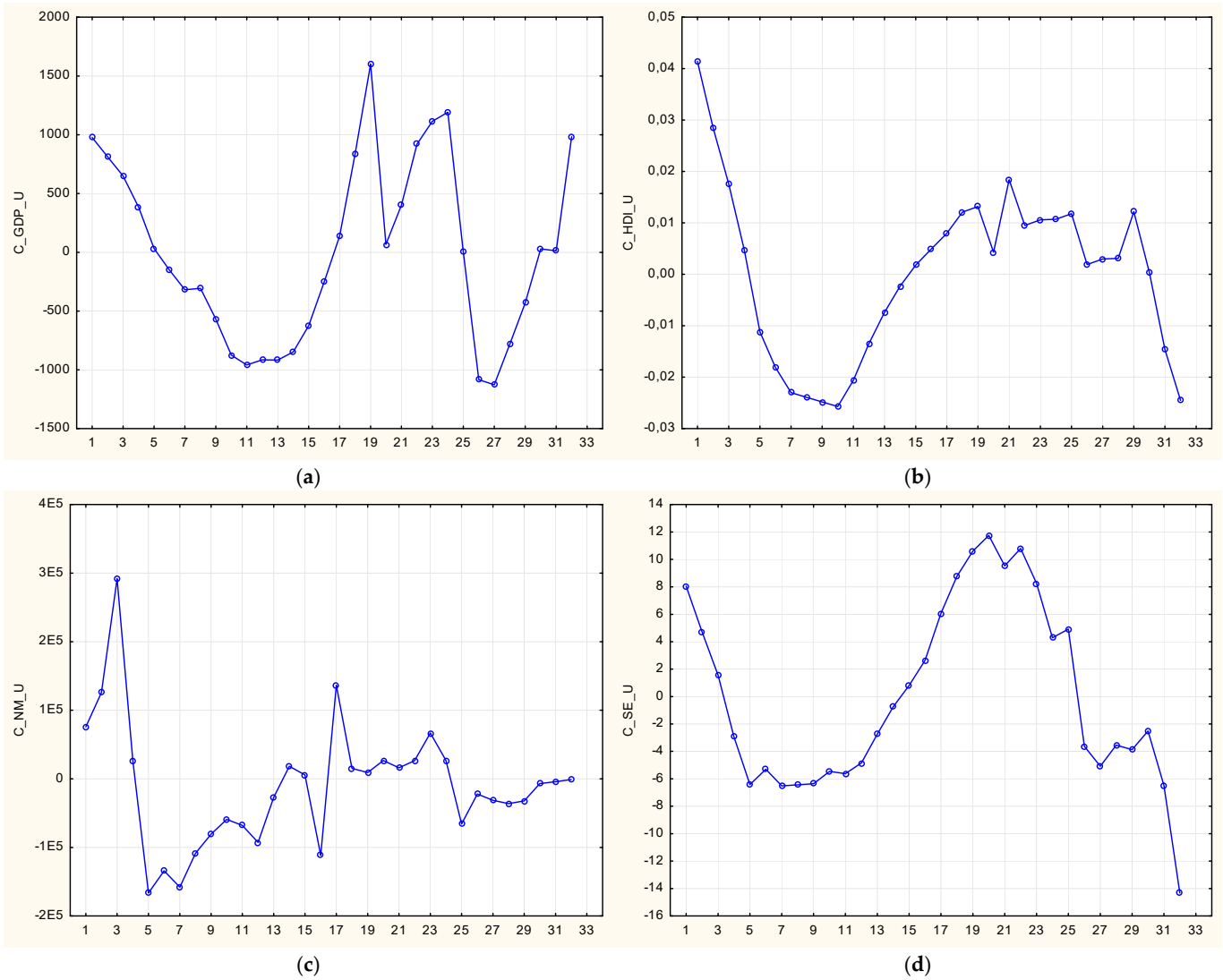


Figure 8. The cyclic components of the time series for Ukraine: (**a**) GDP per capita; (**b**) HDI; (**c**) net migration; (**d**) School enrollment, tertiary (% gross).

Table 3. The determination of the local harmonics of the cyclic components for time series of Slovakia.

Periods (Harmonics)	Cos Coefficient	Sin Coefficient	Periodogram
GDP per Capita (54% *)			
28	−2332.69	−736.889	83,782,463
14	2057.09	1773.415	103,272,582
9.33	−607.29	−62.699	5,218,262
4	−233.53	923.839	12,712,225
HDI **			
28	−0.003369	−0.006847	0.000815
14	0.001833	0.006590	0.000655
9.33	−0.001735	0.001348	0.000068
2	0.001520	0.000783	0.000041
Net Migration (84.3%)			
28	1597.036	237.974	36,500,181
14	344.582	−660.473	7,769,452
9.33	−505.006	−76.564	3,652,498
4	16.039	−458.319	2,944,384

Table 3. *Cont.*

Periods (Harmonics)	Cos Coefficient	Sin Coefficient	Periodogram
School Enrollment, Tertiary (% Gross) (98.6%)			
28	−8.47473	−2.85324	1119.469
14	0.23808	3.86553	209.986
7	0.62066	0.98384	18.944
2.33	0.35496	0.25007	2.639

*—the percentage of the cyclic component described by the given harmonics. **—the HDI for Slovakia is not significant statistically.

The analysis of the data from Table 3 shows the following results for Slovakia:

(1) Four harmonics describe the cyclic components with high-level adequacy, especially for the net migration and school enrollment, tertiary (% gross) time series;
(2) The decomposition of the cyclic component into harmonics for the HDI is statistically insignificant. Therefore, we cannot use the HDI time series for Slovakia in cross-spectral analysis;
(3) Periods 28, 14, and 9.33 years are the most powerful in the cyclic components of the investigated series.

The models of the cyclic component are the combination of the harmonics with different amplitude and frequency. The formula of the cyclic component with four harmonics is outlined below:

$$C(t) = \sum_{k=1}^{4} \left(A_k \cos\left(\frac{2\pi}{T_k}[t-1] \right) + B_k \sin\left(\frac{2\pi}{T_k}[t-1] \right) \right) \quad (5)$$

In Figure 9 we can see real and modeling cyclic components with the coefficients from Table 3.

Analysis of Figure 9 shows that the simulation dates are very close to the real dates. In this case, we can use our Fourier decomposition for the forecasted time series. The cyclic components for the Ukrainian time series are presented in Table 4.

Table 4. Determination of the local harmonics of the cyclic components for time series of Ukraine.

Periods (Harmonics)	Cos Coefficient	Sin Coefficient	Periodogram
GDP per capita (83% *)			
32	83.924	−360.916	2,196,861
16	447.443	670.988	10,406,881
10.67	297.391	−89.240	1,542,480
5.33	26.015	270.493	1,181,490
HDI **			
32	−0.000377	−0.012717	0.002590
16	0.010010	0.004827	0.001976
10.67	0.003043	0.006889	0.000907
8	0.001366	0.005041	0.000436
Net Migration (60.1%)			
32	6328.9	−40,376.5	26,725,010,000
16	62,227.2	16,349.8	66,232,610,000
10.7	43,244.2	23,296.1	38,604,270,000
6.4	−10,247.0	37,205.5	23,828,040,000

Table 4. *Cont.*

Periods (Harmonics)	Cos Coefficient	Sin Coefficient	Periodogram
School Enrollment, Tertiary (% Gross) (82%)			
32	−4.67935	−4.25002	639.3433
16	2.60886	4.21360	392.9697
10.7	1.63436	0.41103	45.4413
5.33	0.11185	1.96365	61.8948

*—the percentage of the cyclic component described by the given harmonics. **—the HDI for Ukraine is not significant statistically.

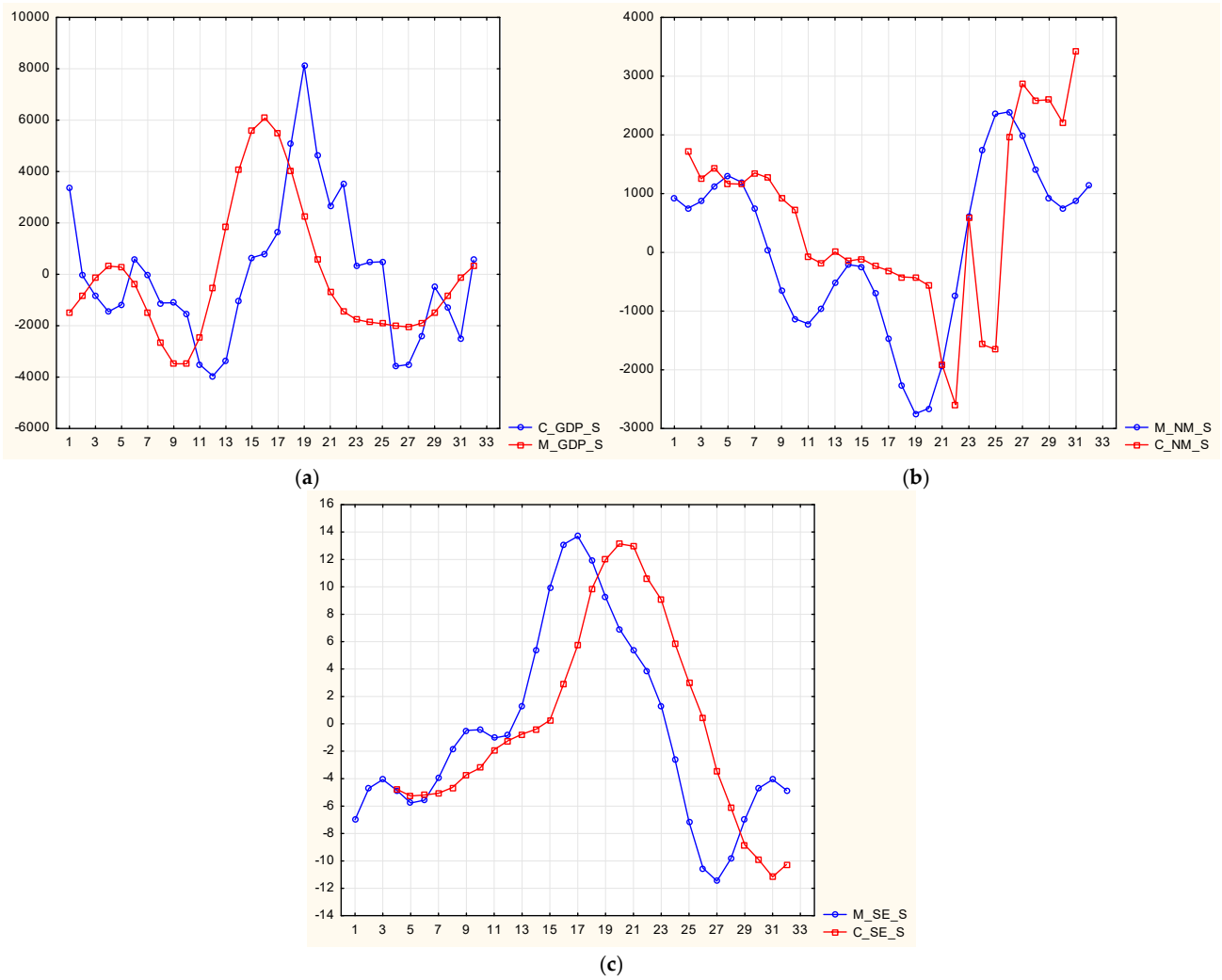


Figure 9. Real and model cyclical components of time series for Slovakia: (**a**) GDP per capita; (**b**) net migration; (**c**) school enrollment, tertiary (% gross).

Analysis of the data from Table 4 shows the following results for Ukraine:

(1) Four harmonics describe the cyclic components with high-level adequacy, especially for the GDP per capita and school enrollment, tertiary (% gross) time series;
(2) The decomposition of the cyclic component into harmonics for the HDI is statistically insignificant. Therefore, we cannot use the HDI time series for Ukraine in cross-spectral analysis;
(3) Periods 32, 16, and 10.7 years are the most powerful in the cyclic components of the studied series.

Combinations of four harmonics in the cyclic components according to Formula (1) are shown in Figure 10.

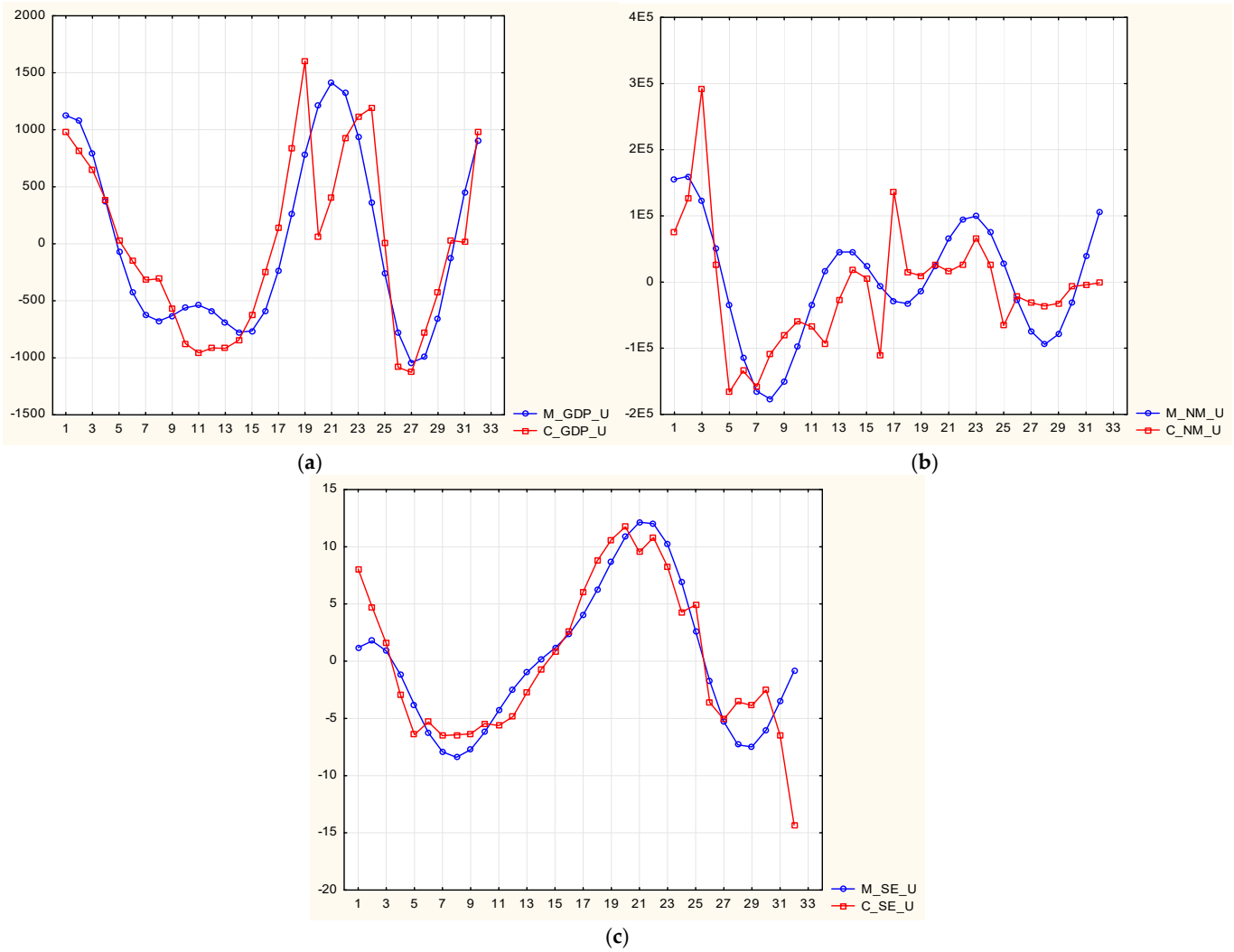


Figure 10. Real and modeling cyclic components of the time series for Ukraine: (**a**) GDP per capita; (**b**) net migration; (**c**) school enrollment, tertiary (% gross).

Figure 10 shows a high-level adequacy of the model of the cyclic components. Therefore, we can use the constructing models in the forecasting of the shocks.

Stage 3. Cross-spectral analysis. At this stage, we investigated the impact of social and economic shocks on the development of higher education. We calculated the following characteristics: cross-amplitude, cross-coherency, and phase spectrum shift. These characteristics are presented in Table 5 for Slovakia.

Table 5. Cross-spectrum analysis for the school enrollment, tertiary (% gross) time series in Slovakia.

Periods (Harmonics)	Cross Amplitude	Squared Coherency	Phase Spectrum
	GDP per Capita		
28	174,618.0	0.786324	0.16
14	128,963.8	0.674899	0.38
9	43,427.2	0.648288	0.64
2.15	478.2	0.586338	1.45

Table 5. *Cont.*

Periods (Harmonics)	Cross Amplitude	Squared Coherency	Phase Spectrum
Net Migration			
28	103,077.3	0.956477	−3.10
14	64,334.9	0.858773	3.06
9	17,182.4	0.637566	2.90
2.112	785.7	0.435656	1.08

Source: Authors' calculations.

The characteristics are calculated for two exogenous factors: GDP per capita and net migration. The HDI factor was excluded from the shock analysis because its spectral density and spectral periodogram were insignificant.

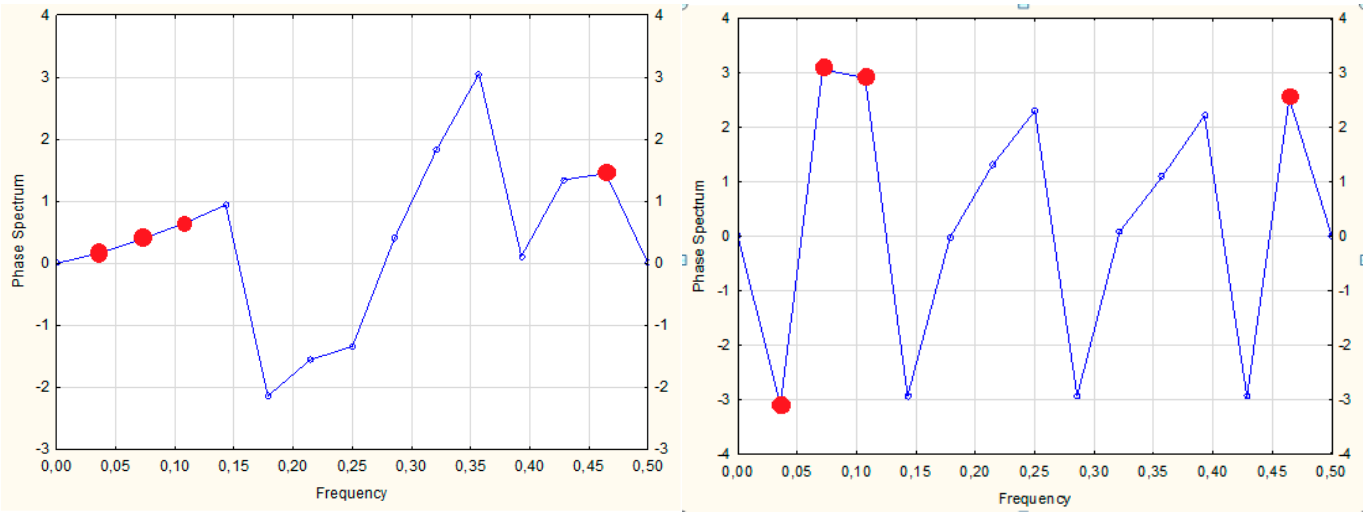
Results of the cross-spectral characteristics analysis for Slovakia include the following:

(1) GDP per capita and net migration have similar coherence periods with school enrollment. Most of the coherence periods are 28, 14, and 9 years. In these periods, the coherences are more than 60%. In the short-term harmonics (2.15 years for GDP per capita and 2.112 years for net migration), the coherences have average values of 58% and 43%, respectively;

(2) The phase shift analysis for GDP per capita shows that all the strongest phase shift values are positive. This means that school enrollment has always delayed its response to changes in the national economy—this delay is less than one year;

(3) There is a lag in the response of GDP per capita and school enrollment to the change in net migration for the four strongest periods of more than 1 year. This means that the impact of net migration has greater inertia than the impact of school enrolment in Slovakia.

The dependencies of the phase spectrum from the frequencies are displayed in Figure 11.



(**a**) (**b**)

Figure 11. The phase shift of the influence of GDP per capita and net migration on school enrollment, tertiary (% gross) in Slovakia: (**a**) GDP per capita; (**b**) net migration. Note that the points of the phase shift corresponding to the harmonics with the greatest coherence are highlighted in red. Source: Authors' calculations.

Figure 11 shows that the phase shifts (red points) of the most significant harmonics (Table 5) for the GDP per capita indicator have positive values. This means that if a shock occurs in the dynamics of this indicator, a shock in the dynamics of the school enrollment, tertiary (% gross) in Slovakia will occur with a lag of 0.16, 0.38, 0.64, and 1.45 years. At the

same time, the net migration indicator (Figure 11) has a higher volatility of the phase shift from −3 to 3 years. For three significant harmonics, the phase shift is positive (Table 5). This means that shock effects in net migration will provoke shock points in the dynamics of the school enrollment, tertiary (% gross) with a lag of 3.06, 2.9, and 1.08 years. For a local harmonic with a period of 28 years and a phase shift of −3 years, the shock to the dynamics of school enrollment, tertiary (% gross) will occur earlier by 3 years.

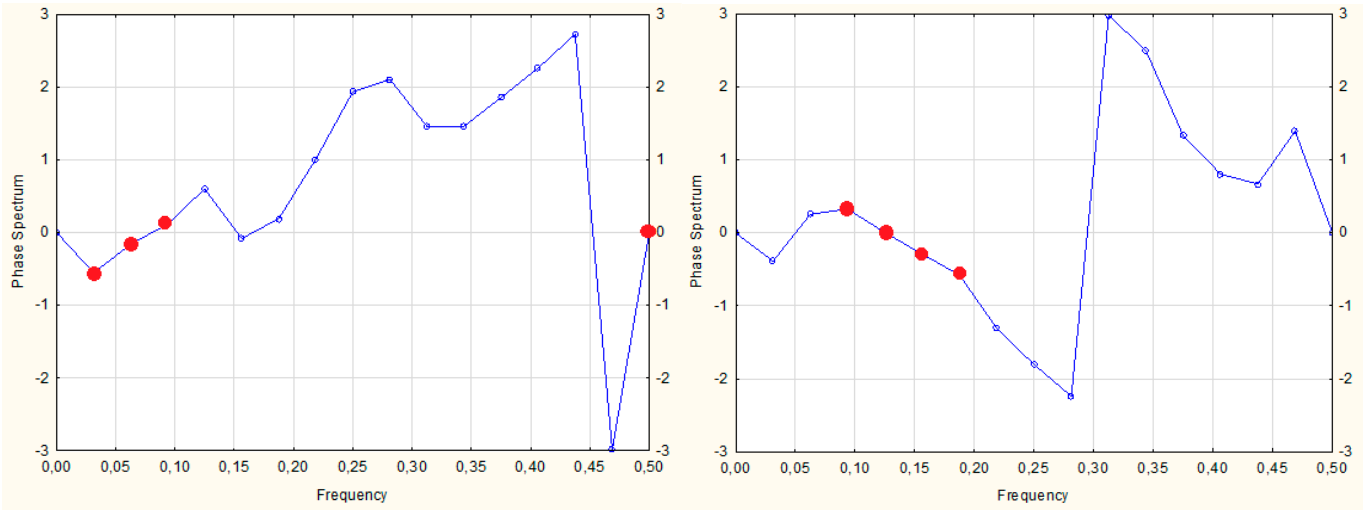
In Table 6 we can see the characteristics of the cross-spectral analysis for Ukraine.

Table 6. Cross-spectrum analysis for the school enrollment, tertiary (% gross) time series of Ukraine.

Periods (Harmonics)	Cross Amplitude	Squared Coherency	Phase Spectrum
GDP per Capita			
32.00000	28,755.68	0.564066	−0.55312
16.00000	35,110.07	0.646984	−0.16393
10.66667	19,121.25	0.717169	0.11739
2.00000	517.85	0.676645	0.00000
Net Migration			
10.66667	1,828,773	0.583530	0.32880
8.00000	957,896	0.774502	0.00588
6.40000	815,322	0.843280	−0.28994
5.33333	677,208	0.583016	−0.57788

If we look at the data from Table 6 for Ukraine, we can see a different picture than for Slovakia. Most powerful coherencies are in the average-term periods (10.67 years for GDP and 8 and 6/4 years for net migration) and short-term periods (2 years for GDP per capita and 5.33 years for net migration). It is the same situation with the signs of the phase shifts—the signs are completely different in Ukraine compared to Slovakia. The lags in the response of school enrolments to changes in GDP per capita and net migration are very small (less than a year and up to six months).

The dependencies of the phase spectrum from the frequencies for Ukraine are shown in Figure 12.



(**a**) (**b**)

Figure 12. The phase shift of the influence of GDP per capita and net migration on school enrollment, tertiary (% gross) for Ukraine: (**a**) GDP per capita; (**b**) net migration (source: Authors' calculations).

The models of cyclical components, phase shifts, and consistency values give us an idea of the impact of economic and social shocks on the development of higher education

in Ukraine. Figure 12 shows that both indicators have a high volatility of phase shift values. Thus, for GDP per capita, the phase shift changes from −3 years to 2.7 years; for the net migration indicator, this is from −2.3 years to 3 years. However, unlike Slovakia, in Ukraine, the most significant harmonics of the indicators (Figure 12, red points) have small lags.

Analysis of the shock effect of GDP per capita on the number of applicants shows that the most significant harmonics have a period of 32, 16, 10.6, and 2 years. For 2 years, the shock in higher education occurs simultaneously with the shock in the dynamics of GDP per capita. For long-term harmonics, the following results were obtained: for 10.6 years, the shock in higher education will occur 0.12 years after the shock in GDP; for harmonics with periods of 16 and 32 years, the shock in school enrollment, tertiary (% gross) will occur with an advance of 0.16 and 0.55 years, respectively.

The most significant harmonics for the net migration indicator are 10.7, 8, 6.4, and 5.3 years (Table 6). Shocks in net migration for 8 years will provoke shock phenomena in school enrollment, tertiary (% gross) almost simultaneously; for 10.7 years, shocks in higher education are typical with a lag of 0.32 years; shocks in the net migration indicator with a period of 6.4 and 5.3 years provoke shocks in higher education with an advance of 0.28 and 0.58 years. Thus, identifying the moments of occurrence of shocks in the functioning of the HES allows for the preventive development of a set of state decisions that will adjust the strategy for the development of higher education as well as the development of a set of measures to support or stimulate the activities of universities.

Another advantage of using the cross-spectral analysis method is the ability to predict the reaction of the higher education system to shocks in the development of the socio-economic environment. Using cross-spectral analysis, the coherence between local harmonics in the school enrollment, tertiary, GDP per capita, and net migration indicators and their phase shift were determined. This allows us to predict shocks to the socio-economic environment for each harmonic and build scenarios of reactions of the higher education system in Slovakia and Ukraine. To predict shocks, we introduce the following definitions:

Positive shock is a local minimum point, characterizing a change in the trend from falling to growing. In forecasting this shock, the Ministry of Education must develop actions to create opportunities for rapid growth of the HES to reduce the period of overcoming past negative trends;

Negative shock is a local maximum point, reflecting a change in the trend from ascending to descending. In this case, the Ministry must develop a set of measures aimed at protecting the national HES from the negative influences of the external world and national environment based on changes in public funding, creating conditions for attracting national and international applicants to the country's HES and increasing its attractiveness to localize negative trends.

The projected values of the shocks to GDP per capita and net migration and the determination of the HES response to these shocks for Ukraine and Slovakia are presented in Table 7.

Table 7. Shocks in GDP per capita and net migration and reaction of shocks in school enrollment, tertiary (% gross) in Slovakia and Ukraine.

Shocks	GDP per Capita	Net Migration	School Enrollment
Slovakia			
Positive	2038–2041 years	2041–2042 years	2039–2041 years
Negative	2031–2032 years 2047–2048 years		2032–2033 years 2048–2049 years

Table 7. *Cont.*

Shocks	GDP per Capita	Net Migration	School Enrollment
	Ukraine		
Positive	2033–2034 years 2049–2050 years	2030–2031 years 2050 year	2032–2033 year 2049–2050 years
Negative	2025–2026 years 2042–2043 years	2025–2026 years 2039 year 2045 year	2025–2026 years 2041–2046 years

Source: Authors' calculations.

The data in Table 7 indicate the following:

(1) For Slovakia, one positive shock is predicted in the dynamics of GDP per capita and net migration, which will form a positive trend in the development of the HES with a lag of 1 year. The emergence of two negative shocks is also expected, which will provoke the emergence of crisis phenomena in the HES with a lag of 1 year;

(2) For Ukraine, two positive and two negative shocks are predicted for the GDP per capita indicator and two positive and three negative shocks for the net migration indicator. They will lead to (1) an increase in the attractiveness of higher education in 2032–2033 and 2049–2050. In this case, it is advisable to implement the scenario of intensive development and the creation of prerequisites for the activation of Ukraine's HES in the national and international educational markets; (2) the emergence of crisis phenomena in 2025–2026 and 2041–2046. In such conditions, a scenario and various measures to support the development of the country's HES should be formed.

That is, as calculations have shown, the delay in the reaction of the HES of Slovakia is 1 year, while the Ukrainian HES reacts to shocks in the socio-economic environment without a lag delay. This conclusion is confirmed by the graphical representation of the models of cyclical components for the analyzed indicators (Figure 13), which also reflects the forecast values of the indicator of school enrollment, tertiary (% gross) for Ukraine and Slovakia, considering certain lags in the delay of reactions to shocks in the external environment.

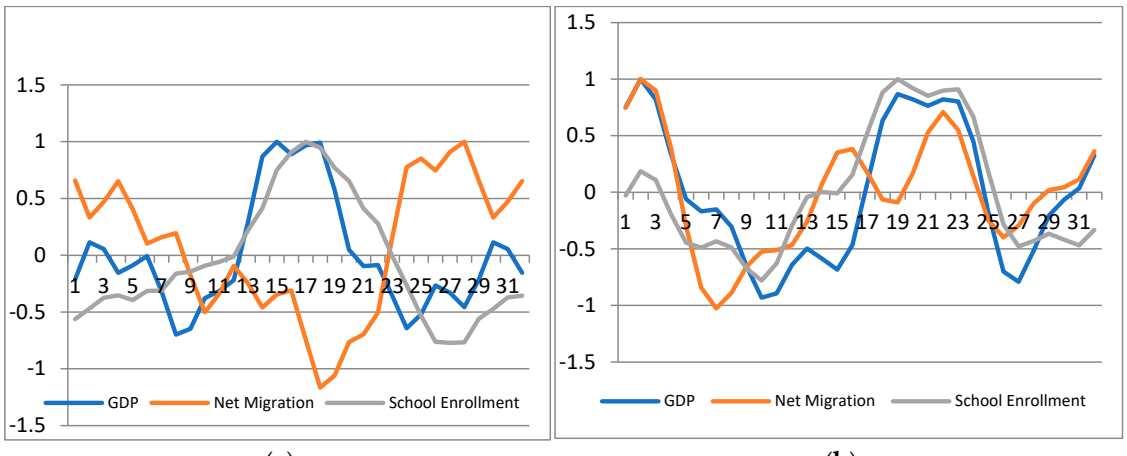


Figure 13. Estimated values of the cyclical component for indicators of GDP per capita, net migration, and forecast responses of number of entrants: (**a**) Slovakia; (**b**) Ukraine (source: Authors' calculations).

Thus, Hypothesis 3 has been confirmed using the selected mathematical tools—the time-series decomposition method, single Fourier analysis, and cross-spectral analysis.

5. Discussion

In the framework of this study, the use of aggregated indicators of socio-economic development and the system of higher education is important. According to the Sustainable Development Goals, one of the aims of sustainable development is to ensure inclusive and equitable quality education and lifelong learning opportunities for all (United Nations 2022, 2023). Therefore, in our opinion, as an aggregate indicator, it is appropriate to use the school enrollment indicator, which reflects the attractiveness of higher education due to the number of students entering universities. These findings correlate with studies (Cao et al. 2024; Kurylo and Karaman 2023; Kremen et al. 2023; Levchuk 2024; Algirdas and Tomas 2023; Batool and Liu 2021), which also state that one of the indicators of the effectiveness of the higher education system is the number enrolled/graduated students.

In this study, GDP per capita and net migration were selected as indicators of the socio-economic environment of the higher education system, and although there are many indicators of socio-economic development, examining the impacts on the higher education system is a strength of this study. However, an important aspect is finding a balance between the micro-description of the research object and aggregation. Therefore, based on the content analysis and research of a number of studies devoted to migration processes, the choice was based on the use of these two indicators. In addition, the authors (Mahato et al. 2022; Chowdhury 2019; Cheng et al. 2023; Stojanovski et al. 2023) determined that migration processes influence the development of the educational system and (Kalmukhanbetova and Shnarbekova 2022) determined that educational migration largely influences the dynamics and character of the country's socio-economic development.

From the point of view of studying the interaction of the higher education system with the socio-economic environment, it is important to highlight long-term and short-term trends. To achieve the goal of this research, emphasis was placed on the study of short-term trends, which are represented by a cyclical component. Therefore, the method of cross-spectral analysis was used, which made it possible to determine shocks in the development of the socio-economic environment of the higher education system and their impact on it. From the point of view of long-term co-integration between the socio-economic environment and the system of higher education, it is appropriate to use VAR models, which, in turn, allows for conducting impulse analysis and identifying shocks in long-term trends.

Of course, in these studies, the choice of mathematical methods and models for approximating processes has a strong influence. Without reducing the opinion on the effectiveness of spectral analysis, it is necessary to note the following. The Fourier transform has one drawback, namely, it starts again after the last observation, which limits forecasting in the long-term management horizon. To eliminate this disadvantage, it is interesting to use wavelet analysis.

In addition, in our study, we took three exogenous factors that significantly change the behavior of higher education. However, it would be interesting to expand the list of these indicators, which would allow for using long-term models with memory and aperiodic methods to study cyclical components.

6. Conclusions

To achieve the objective of this study, the following results were obtained:

An algorithmic model has been developed that allows diagnosing shock points in the country's socio-economic development and their impact on the development trends of the higher education system. The conceptual basis of the model is a set of research hypotheses that determine its objective.

Practical implementation of the algorithmic model allows us to develop a set of recommendations and solutions aimed at increasing the sustainability and attractiveness of the higher education system through timely monitoring of the reactions of the higher education system to socio-economic shocks. Also, the proposed model has practical significance for management at the state- and university-levels when forming the strategy and tactics of

functioning, considering resource capabilities and disturbances of the external environment. This creates the prerequisites for making effective decisions to increase the competitiveness of the national higher education system in the global educational space and ensure all its vital functions.

To prove the first two hypotheses, an information space of the study was formed, including four indicators that reflect economic, social, and demographic development and the development of the higher education system for 1990–2023. The constructed portraits of the socio-economic development of Ukraine and Slovakia showed the presence of consistent trends in the change in the indicators of GDP per capita, the Human Development Index, coverage of tertiary school education, and net migration. The nonlinear nature of the change in these indicators and the definition of local minimum points in their trends made it possible to confirm the hypothesis about the influence of social and economic factors on the higher education system of these countries.

The complex interactions between the higher education system and socio-economic factors made it possible to justify the feasibility of using a special model basis, namely, the time-series decomposition methods and cross-spectral analysis (third hypothesis). A detailed analysis of the four indicators for the presence of a trend in dispersion and average showed that all indicators have cyclical components. However, the cyclical component of the HDI is not significant, therefore, we excluded this indicator from our study. Thus, to determine the impact of shocks in the external environment on higher education, the indicators of GDP per capita and net migration were used.

To achieve the objective of this study, we considered the shock from two sides. On the one hand, we made one Fourier transform, which helped us find the strongest harmonics and determine the modeling period of the cyclical component. For this purpose, we analyzed each time series separately without their mutual influence. On the other hand, we used cross-spectral analysis, which shows us the coherence between harmonics from different time series with different amplitudes, periods, and frequencies. Calculation of the three main characteristics of cross-spectral analysis (cross-amplitude, coherence, and phase shift) allowed us to identify the closest harmonics in the analyzed time series. Studying the phase shift allowed us to determine the delay in the reaction of higher education (school enrollment, tertiary, %) to shocks in economic (GDP per capita) and social (net migration) development. The results showed that the HES in Slovakia reacts to socio-economic shocks with a one-year lag; the Ukrainian HES is sensitive to them and reacts without delay.

With the help of the constructed models, positive and negative shocks in the socio-economic environment of the higher education system were determined, which allowed for proposing scenarios of the behavior of the country's higher education management. The first is implemented when negative shocks appear and is aimed at supporting the HES to maintain its attractiveness for national and foreign applicants, and the second is used with positive shocks and is aimed at stimulating the activities of universities through innovative and active, entrepreneurial behavior in the educational services market. Shock periods in the indicators of GDP per capita and net migration were predicted. Using a phase shift, points of positive and negative shocks for the higher education system of Ukraine and Slovakia were determined.

The obtained results and questions for discussion determine further directions of research. Of particular interest is the expansion of the list of indicators of the socio-economic environment that influence the functioning of a country's HES. For example, it is advisable to consider the influence of indicators such as the income of the population, the quality of life of the population, the cost of education, the quality of educational services, the level of security, etc. In addition, it would be interesting to study the use of VAR models and wavelet analysis to assess the long-term co-integration of harmonics of cyclical components and to forecast the short-term emergence of shock phenomena.

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Appendix A

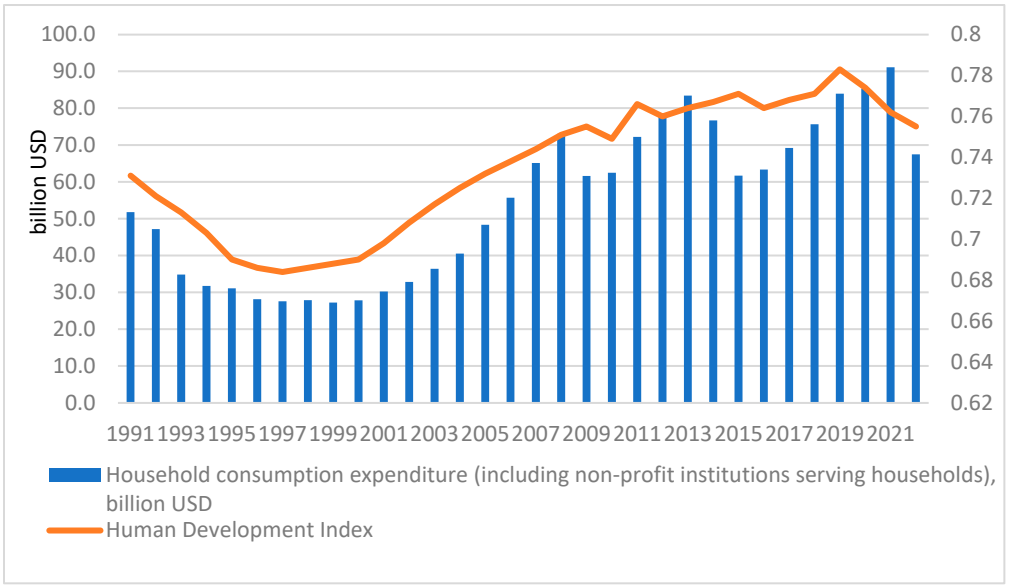

Figure A1. HDI trend for Ukraine (Website World Data Atlas n.d.; Website World Bank n.d.).

References

Agasisti, Tommaso, and Olesya Petrenko. 2024. Higher education and economic development: A bibliometric analysis 1985–2022. *European Journal of Education* 59: e12653. [CrossRef]

Algirdas, Pupkis, and Saulius Tomas. 2023. Higher education: Academic freedom and social responsibility. *Humanities Studies* 17: 127. [CrossRef]

Andronic, Adrian. 2023. An examination of financing strategies for the digital transformation of universities in developed countries. In *Strategii şi politici de management în economia contemporană [Resursă electronică]: Conf. şt. Intern., Ediția a 8-a, 24–25 martie 2023*. Chişinău: SEP ASEM, pp. 382–90. ISBN 978-9975-147-99-6.

Appiah, Elizabeth N. 2017. The Effect of Education Expenditure on Per Capita GDP in Developing Countries. *International Journal of Economics and Finance* 9: 136–44. [CrossRef]

Ashirbekova, Dinara A., and Gulnara Z. Nurmukhanova. 2022. Financing high education in the context of new challenges. *Bulletin of Turan University* 1: 297–305. [CrossRef]

Batool, Syeda Mubashira, and Zhimin Liu. 2021. Exploring the relationships between social-economic indicators and student enrollment in higher education institutions of Pakistan. *PLoS ONE* 16: e0261577. [CrossRef] [PubMed] [PubMed Central]

Bloomfield, Peter. 2000. *Fourier Analysis of Time Series: An Introduction*. Wiley Series in Probability and Statistics; Hoboken: John Wiley & Sons, Inc. ISBN 0-471-88948-2.

Box, George E. P., and Gwilym M. Jenkins. 1976. *Time Series Analysis: Forecasting and Control*, rev. ed. San Francisco: Holden Day.

Bredyuk, Vladimir, and Olena Joshi. 2017. The econometric modeling of higher education system in the modern labor market. *International Journal of New Economics and Social Sciences (IJONESS)* 5: 29–43. [CrossRef]

Brigham, E. Oran. 1974. *The Fast Fourier Transform*. Englewood Cliffs: Prentice-Hall.

Brillinger, David R. 1975. The Identification of Point Process Systems. *The Annals of Probability* 3: 909–24. [CrossRef]

Canova, Fabio, and Matteo Ciccarelli. 2013. *VAR Models in Macroeconomics—New Developments and Applications: Essays in Honor of Christopher A. Sims*. Bingley: Emerald Publishing Limited.

Cao, Xiaojie, Weifang Min, and Xinqiao Liu. 2024. Exploring the Relationship between Higher Education and Common Prosperity: A Global Perspective and Insights from China. In *Innovation and Evolution in Tertiary Education*. London: techOpen. [CrossRef]
Charles, Daniel, and Daniel Samon. 2023. The Crossroads of Finance and Education, Managing the Financial Environment of Education, December 2023. Available online: https://ur0.jp/QyUuJ (accessed on 19 July 2024).
Cheng, Yi'En, Peidong Yang, Jihyun Lee, Johanna Waters, and Brenda S. A. Yeoh. 2023. Migration governance and higher education during a pandemic: Policy (mis)alignments and international postgraduate students' experiences in Singapore and the UK. *Journal of Ethnic and Migration Studies* 50: 1138–56. [CrossRef]
Cherednichenko, I., and Yu. Gustchina. 2016. Higher education as a factor in the social-economic transformation of society. *Russian Entrepreneurship* 17: 3431. [CrossRef]
Chetyrbock, Natallia. 2023. Education as a determining factor of national competitiveness. *Education in the 21st Century* 9: 65–74. [CrossRef]
Chowdhury, Mamta. 2019. Importance of Institutional Quality in Managing Manpower Resources and Remittances. Paper presented at 2nd International Conference on Business and Economics: Interdisciplinary Solutions for Business Challenges in a New Global Order, Dhaka, Bangladesh, March. Available online: https://www.researchgate.net/publication/331887685_Importance_of_Institutional_Quality_in_Managing_Manpower_Resources_and_Remittances (accessed on 17 July 2024).
Department of Economic and Social Affairs of United Nations. n.d. Available online: https://unstats.un.org/sdgs/dataportal (accessed on 18 July 2024).
Dimoso, Romanus L. 2024. Exploring the Relationship between GDP Per Capita, Government Expenditure, and Poverty Reduction in Tanzania. *NG Journal of Social Development* 13: 106–22. [CrossRef]
Elliott, Douglas F., and K. Ramamohan Rao. 1982. *Fast Transforms: Algorithms, Analyses, Applications*. New York: Academic Press. 488p, ISBN 0-12-237080-5.
European Commission, Directorate-General for Education, Youth, Sport and Culture. 2022. *Education and Training Monitor 2022—Comparative Report*. Luxembourg: Publications Office of the European Union. Available online: https://data.europa.eu/doi/10.2766/117416 (accessed on 20 July 2024).
European Commission, Directorate-General for Education, Youth, Sport and Culture. 2023. *Education and Training Monitor 2023—Comparative Report*. Luxembourg: Publications Office of the European Union. Available online: https://data.europa.eu/doi/10.2766/936303 (accessed on 20 July 2024).
European Commission, European Education and Culture Executive Agency. 2022a. *Supporting Refugee Learners from Ukraine in Higher Education in Europe*. Luxembourg: Publications Office of the European Union. Available online: https://data.europa.eu/doi/10.2797/022188 (accessed on 20 July 2024).
European Commission, European Education and Culture Executive Agency. 2022b. *Towards Equity and Inclusion in Higher Education in Europe*. Luxembourg: Publications Office of the European Union. Available online: https://data.europa.eu/doi/10.2797/631280 (accessed on 20 July 2024).
European Commission, European Education and Culture Executive Agency. 2024. *Validation of Non-Formal and Informal Learning in Higher Education in Europe—Eurydice Report*. Luxembourg: Publications Office of the European Union. Available online: https://data.europa.eu/doi/10.2797/296107 (accessed on 20 July 2024).
European Commission's Directorate-General for Education, Youth, Sport and Culture. 2023. Education and Training Monitor 2023 Comparative Report. Available online: https://op.europa.eu/en/publication-detail/-/publication/2d4c4524-8e68-11ee-8aa6-01aa75ed71a1/language-en/format-PDF/source-297481971 (accessed on 20 July 2024).
European Education and Culture Executive Agency, Eurydice. 2023a. *Mobility Scoreboard—Higher Education Background Report 2022/2023—Eurydice Report*. Luxembourg: Publications Office of the European Union. Available online: https://data.europa.eu/doi/10.2797/001589 (accessed on 21 July 2024).
European Education and Culture Executive Agency, Eurydice. 2023b. *Structural Indicators for Monitoring Education and Training Systems in Europe 2023—Higher Education*. Luxembourg: Publications Office of the European Union. Available online: https://data.europa.eu/doi/10.2797/790501 (accessed on 21 July 2024).
European Education and Culture Executive Agency, Eurydice. 2024. *The European Higher Education Area in 2024—Bologna Process Implementation Report*. Luxembourg: Publications Office of the European Union. Available online: https://data.europa.eu/doi/10.2797/483185 (accessed on 21 July 2024).
Fatima, Noor, Muhammad Imran Ashraf, and Sania Zehra. 2020. Higher Education Policy & Research in Pakistan: Challenges in Transformation of the Society and the Way Forward. *Universal Journal of Educational Research* 8: 2842–52. [CrossRef]
Ferreiro-Seoane, Francisco-Jesús, Manuel Octavio del Campo Villares, Nerea Abad-Itoiz, and Eladio Jardón Ferreiro. 2024. Social-economic Determinants of the Value Attributed to Human Capital in the Labour Market from the Employee's Perspective. *Administrative Sciences* 14: 154. [CrossRef]
Garashchuk, Olena, and Vira Kutsenko. 2024. Simulation the future of sustainable development: Educational environment its provision. *Herald of Economics* 1: 8–20. [CrossRef]
Hrabchuk, Oksana, Liubov Lysiak, and Olena Zarutska. 2022. Diversification of sources of financing higher education: The experience of reform in European countries. *AD ALTA: Journal of Interdisciplinary Research* 12/01-XXV: 143–47. [CrossRef]
Kalmukhanbetova, M., and M. Shnarbekova. 2022. Educational migration: Reasons and features of obtaining higher education abroad. *Bulletin Series of Sociological and Political Sciences* 1: 67–76. [CrossRef]

Korobilis, Dimitris. 2019. Forecasting with High-Dimensional Panel VARs. *Oxford Bulletin of Economics & Statistics* 81: 937–59. [CrossRef]
Kremen, V. G., V. I. Lugovyi, P. Yu. Saukh, I. I. Drach, O. M. Slyusarenko, Yu. A. Skiba, O. V. Zhabenko, S. A. Kalashnikova, Zh. V. Talanova, O. M. Petroye, and et al. 2023. *Higher Education of Ukraine in the Conditions of War and Post-War Recovery: Challenges and Answers: Scientific and Analytical Report*. Edited by V. G. Flint. Kyiv: Pedagogical Thought. 172p. [CrossRef]
Kurylo, Vitaliy, and Elena Karaman. 2023. Higher education in Ukraine under martial law: "DISPLACED UNIVERSITIES": Scientific report at the joint meeting of the Committee of Pedagogical Sciences of the Polish Academy of Sciences and the Academic Council of Luhansk Taras Shevchenko National University on September 29, 2023. *Herald of the National Academy of Educational Sciences of Ukraine* 5: 1–8. [CrossRef]
Larchenko, O. 2023. The efficiency analysis of the mathematical modeling methods application in the economy. *Visnyk of Kherson National Technical University* 2: 163–67. [CrossRef]
Levchuk, Kateryna. 2024. Higher education in Ukraine under martial law: Challenges and ways of recovery. *Eastern Europe: Economy, Business and Management* 2: 57–61. [CrossRef]
Li, Jian, Eryong Xue, Yukai Wei, and Yunshu He. 2024. How popularising higher education affects economic growth and poverty alleviation: Empirical evidence from 38 countries. *Humanities and Social Sciences Communications* 11: 520. [CrossRef]
Mahato, Santosh K., Devi Prasad Paudel, and Om Prasad Baral. 2022. Motivating Factors of Youth Selecting Labor Migration Rather Than Higher Education: A Systematic Review. *Interdisciplinary Research in Education* 7: 115–28. [CrossRef]
Marto, Marco, João Lourenço Marques, and Mara Madaleno. 2022. An Evaluation of the Efficiency of Tertiary Education in the Explanation of the Performance of GDP per Capita Applying Data Envelopment Analysis (DEA). *Sustainability* 14: 5524. [CrossRef]
Migration Data Portal. n.d. Available online: https://www.migrationdataportal.org/data-catalogue (accessed on 22 July 2024).
Mirgorodskaya, Elena, Svetlana Sokolova, Tatyana Kuzmina, and Maria Shkuratova. 2023. Transformation of the higher education system: Current and emerging global trends. *E3S Web of Conferences* 431: 09013. [CrossRef]
Munir, Javeria, Mehreen Faiza, Bakht Jamal, Sana Daud, and Khurshed Iqbal. 2023. The Impact of Social-economic Status on Academic Achievement. *Journal of Social Sciences Review* 3: 695–705. [CrossRef]
OECD. 2022. *Education at a Glance 2022: OECD Indicators*. Paris: OECD Publishing. [CrossRef]
OECD. 2023. *Education at a Glance 2023: OECD Indicators*. Paris: OECD Publishing. [CrossRef]
OECD Data. n.d. Available online: https://www.oecd.org/en/data/indicators.html?orderBy=mostRelevant&page=0 (accessed on 22 July 2024).
Official Website of the Parliament of Ukraine. n.d. Verkhovna Rada of Ukraine. Available online: https://zakon.rada.gov.ua/laws/main?lang=en (accessed on 21 July 2024).
Panigrahi, Jinusha. 2023. Financing of Public Higher Education Institutions in India. In *Financing of Higher Education*. Edited by N. Varghese and J. Panigrahi. Singapore: Springer. [CrossRef]
Pelletier, Kathe, Malcolm Brown, D. Christopher Brooks, Mark McCormack, Jamie Reeves, Nichole Arbino, Aras Bozkurt, Steven Crawford, Laura Czerniewicz, Rob Gibson, and et al. 2022. *2022 EDUCAUSE Horizon Report, Teaching and Learning Edition*. Boulder: EDUCAUSE. Available online: https://library.educause.edu/-/media/files/library/2022/4/2022hrteachinglearning.pdf (accessed on 21 July 2024).
Pelletier, Kathe, Mark McCormack, Nicole Muscanell, Jamie Reeves, Jenay Robert, and Nichole Arbino. 2024. *2024 EDUCAUSE Horizon Report, Teaching and Learning Edition*. Boulder: EDUCAUSE. Available online: https://library.educause.edu/-/media/files/library/2024/5/2024hrteachinglearning.pdf (accessed on 21 July 2024).
Pettenuzzo, Davide, and Allan Timmermann. 2017. Forecasting Macroeconomic Variables Under Model Instability. *Journal of Business & Economic Statistics* 35: 183–201. [CrossRef]
Priestley, M. B. 1981. *Spectral Analysis and Time Series*. New York: Academic Press Inc.
Prus, Alla. 2023. Mathematical modeling as a lens of the real world. *Physical and Mathematical Education* 38: 56–61. [CrossRef]
Rayevnyeva, Olena, Kostyantyn Stryzhychenko, and Silvia Matúšová. 2023a. Impact of Migration Processes on GDP. *Engineering Proceedings* 39: 86. [CrossRef]
Rayevnyeva, Olena, Volodymyr Ponomarenko, Silvia Matúšová, Olha Brovko, and Ľubica Filipová. 2023b. The transformation of the country's higher education system under the influence of migration processes. *Entrepreneurship and Sustainability* 11: 259–81. [CrossRef]
Reinitz, Betsy Tippens, Mark McCormack, Jamie Reeves, Jenay Robert, Nichole Arbino, Jeremy Anderson, John Hamman, Connie Johnson, Olivia Kew-Fickus, Rob Snyder, and et al. 2022. 2022 EDUCAUSE Horizon Report, Data and Analytics Edition. Available online: https://library.educause.edu/-/media/files/library/2022/7/2022hrdataandanalytics.pdf (accessed on 19 July 2024).
SDG Summit. 2023. Website United Nations. Available online: https://www.un.org/en/conferences/SDGSummit2023 (accessed on 16 July 2024).
Shafiq, M. Najeeb. 2010. The Effect of an Economic Crisis on Educational Outcomes: An Economic Framework and Review of the Evidence. *Current Issues in Comparative Education* 12: 5–13.
Shapor, Maria. 2021. Review of Foreign Experience in Assessing the Impact of Qualitative Indicators on Economic Processes Using Vector Autoregression Models. *SSRN Electronic Journal*. [CrossRef]

Sheriffdeen, Kayode, Edwin Frank, and Godwin Olaoye. 2024. Public-Private Partnerships in Addressing the Digital Divide. Available online: https://www.researchgate.net/publication/378705456_Public-private_partnerships_in_addressing_the_digital_divide#fullTextFileContent (accessed on 16 July 2024).
Shumway, Robert H., and David S. Stoffer. 2017. *Time Series Analysis and Its Applications: With R Examples*, 4th ed. New York: Springer. ISBN 978-3-319-52451-1.
Sims, Christopher. 1980. Macroeconomics and reality. *Econometrica* 48: 1–48. [CrossRef]
Stojanovski, Strashko, Ana Paneva, and Kristijan Panev. 2023. Youth, migration and higher education. *Balkan Social Science Review* 22: 271–93. [CrossRef]
Sushchenko, Olena, Kateryna Kasenkova, and Serhii Sushchenko. 2022. Innovative marketing technologies in the development of the tourism specialized types. *Business Management* 3: 5–16. Available online: http://hdl.handle.net/10610/4693 (accessed on 20 July 2024).
The UNESCO Institute for Statistics. n.d. Available online: https://data.uis.unesco.org/Index.aspx (accessed on 16 July 2024).
UNESDOC. 1960. Convention Against Discrimination in Education. Paper presented at the General Conference of the UNESCO, Paris, France, November 14–December. Available online: https://unesdoc.unesco.org/ark:/48223/pf0000183342 (accessed on 17 July 2024).
UNESDOC. 2015. Education 2030: Incheon Declaration and Framework for Action for the implementation of Sustainable Development Goal 4: Ensure Inclusive and Equitable Quality Education and Promote Lifelong Learning Opportunities for All. Paper presented at the World Education Forum, Incheon, Republic of Korea, May 19–22. Available online: https://unesdoc.unesco.org/ark:/48223/pf0000245656 (accessed on 18 July 2024).
UNESDOC. 2019. Global Convention on the Recognition of Qualifications Concerning Higher Education. Paper presented at the General Conference of the UNESCO, Paris, France, November 12–27. Available online: https://unesdoc.unesco.org/ark:/48223/pf0000373602/PDF/373602eng.pdf.multi.page=3 (accessed on 22 July 2024).
UNESDOC. 2023. Report on the Regional Recognition Conventions. Paper presented at the 1st Intergovernmental Conference of the States Parties to the Global Convention on the Recognition of Qualifications concerning Higher Education, Paris, France, July 4–5. Available online: https://unesdoc.unesco.org/ark:/48223/pf0000385741 (accessed on 16 July 2024).
United Nations. 2022. The Sustainable Development Goals Report 2022. Available online: https://unstats.un.org/sdgs/report/2022/The-Sustainable-Development-Goals-Report-2022.pdf (accessed on 16 July 2024).
United Nations. 2023. The Sustainable Development Goals Report 2023: Special Edition Towards a Rescue Plan for People and Planet. Available online: https://unstats.un.org/sdgs/report/2023/The-Sustainable-Development-Goals-Report-2023.pdf (accessed on 16 July 2024).
Volchik, Vyacheslav, Anna Oganesyan, and Tadeusz Olejarz. 2018. Higher education as a factor of social-economic performance and development. *Journal of International Studies* 11: 326–40. [CrossRef]
Website Education Counts. n.d. Available online: https://www.educationcounts.govt.nz/home (accessed on 21 July 2024).
Website International Association of Universities. n.d. Available online: https://www.iau-aiu.net/ (accessed on 22 July 2024).
Website OECD. 2024. Education GPS. The World of Education at Your Fingertips. Available online: https://ur0.jp/cijmL (accessed on 22 July 2024).
Website of Eurostat. n.d. Available online: https://ec.europa.eu/ (accessed on 16 July 2024).
Website Statista. n.d. Available online: https://www.statista.com (accessed on 16 July 2024).
Website United Nations Development Programme (UNDP). n.d. Available online: https://www.undp.org/ (accessed on 16 July 2024).
Website World Bank. n.d. Available online: https://www.worldbank.org/en/home (accessed on 16 July 2024).
Website World Data Atlas. n.d. Available online: https://knoema.com/ (accessed on 16 July 2024).
Wei, W. 1989. *Time Series Analysis: Univariate and Multivariate Methods*. New York: Addison-Wesley.
Wen, Yuyao. 2023. Exploring the GDP-Education Relationship: A Comparative Study of Developing and Developed Nations. *Advances in Economics, Management and Political Sciences* 61: 182–91. [CrossRef]