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Digitalization's Effect on the Sectoral Structure Change in the Economy: a Comparative Analysis of Ukraine and Selected Countries

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Abstract

This article examines the impact of digital transformation on changes in the sectoral structure of Ukraine's economy, other post-communist countries, and countries with highly developed economies. Firstly, we estimate the structural changes and differences in the sectoral model by gross value-added and sectoral employment model by country using Ryabtsev's index. Secondly, we calculated the forecast of changes in the researched economies' sectoral structures for 2021 and 2025 using discrete Markov processes. The forecasts made it possible to determine the direction of socio-economic progress of highly developed and post-communist countries. Thirdly, assuming that the development of ICT technologies caused the sectoral changes identified as a result of the assessment, we analyzed available level ratings of the digital transformation of the selected economies and named global trends in ICT. Finally, we determined the impact of the ICT index on the substantiality of sectoral changes in the economies of post-communist countries and countries with highly developed economies. The study results allowed us to conclude that digital technology development affects the economy's structural changes indirectly due to the reallocation of labor resources from one sector to another. The article substantiates the need to

improve the economy's sectoral model by adding industries related exclusively to the digital economy.

Keywords: the sectoral structure of the economy, digital transformation, Markov chains, gross value added, the sectoral structure of employment

JEL: O11, O33, O57

Introduction

The world is changing. These changes are primarily related to the generation, transmission, storage, management, and analysis of information, making it the most critical production resource today. Countless information flows structure the modern world, changing people's consciousness and vital activity forms. Digital technologies, which have become one of the most powerful drivers of the world's economy, are changing society's development paradigm. They reduce economic growth dependency on the country's natural resources, able-bodied population, fixed capital and other extensive factors of influence.

A paradigm shift determines a society's transition to an entirely new development level, which is associated with the economic system's digital transformation. These processes were confirmed by Hilbert and Lopez, to some extent, who stated that a significant part of technological memory (94% in 2007) is already in digital format (Hilbert and Lopez 2011). In turn, the number and volume of individual elements of material production (buildings, structures, bank equipment) are being reduced the non-digital economy becomes digital. Nevertheless, the development of information technology does not abolish material production, nor does it reduce the role of industry and agriculture. However, most people begin to create, collect, store, process, and disseminate information rather than participate in direct production.

The purpose of this article is to determine the impact of digital transformation on structural changes and differences in sectoral models of the economy of Ukraine, other post-communist countries, and countries with highly developed economies. Firstly, we analyzed scientific views on the economy's sectoral structures (Fisher 1939; Clark 1940; Fourastié 1949) to achieve this goal. Secondly, we built a basic sectoral model[1] of the national economy that considers modern standards of sectoral classifi-

1 Note: By the basic sector model, we understand a five-sector model where 1) the primary sector includes agriculture, forestry, fisheries, mining and activities of households; 2) the secondary sector includes manufacturing and construction; 3) the tertiary includes electricity, gas, steam and air conditioning supply, water supply, sewerage, waste management and remediation activities, wholesale and retail trade, repair of motor vehicles and motorcycles, transportation and storage; 4) the quaternary includes accommodation and food service activities, Information and communication, financial and insurance activities, real estate activities, administrative and support service activities, other service activities; 5) the quinary includes professional, scientific and technical activities, public administration and defence, compulsory social security, education, human health

cation of the economic activities (ISIC, United Nations) and assesses structural changes and differences in the selected countries economies by technological criteria.

The article's starting point is the assumption that digitalization is one of the most significant factors that influence sectoral structural changes in the economy of countries of any level of development (both in terms of gross value added and employment). On the one hand, digital technologies contribute to the development of services by opening global markets. On the other hand, the digital transformation is causing widespread automatization of production and a significant reduction in employment, especially in the economy's primary and secondary sectors.

There has been empirical research of national economic structures from 2001 to 2019 in post-communist countries, which transitioned from an administrative command economy to a market economy. On the one hand, this group of countries can be called homogeneous. Some of them were formed after the collapse of communist federations in the late 1980s, such as Czechoslovakia, the Soviet Union, Yugoslavia. On the other hand, the former communist countries differ in the starting opportunities for implementing reforms, the pace and nature of their performance, and the results. Therefore, countries with transformational economies should be explored in three groups:

1. a group of countries characterized by the short existence of a planned economy (by historical standards) – about 40 years, and in a less rigid version than the USSR. These countries are members of the EU and are de jure equated to developed economies (Poland, Hungary, Slovakia, Czech Republic);
2. countries that have recently obtained EU membership. Furthermore, they are characterized by the long-term existence of an administrative-command system (Bulgaria, Romania);
3. countries characterized by the long-term administrative-command system for more than 70 years in its most rigid variant (Ukraine, Russia, Belarus, Georgia).

In addition to the post-communist countries, this study will place significant emphasis on the leading countries by different evaluation criteria, in particular: in terms of GDP – the USA, China, Japan, Germany, Great Britain, France; GDP per capita – Luxembourg, Norway, Switzerland; the global HDI rating – Australia. Most of these countries are at the forefront of post-industrial processes, and they serve as a transition model for post-industrial economic development for many countries worldwide.

and social work activities, arts, entertainment and recreation, activities of extraterritorial organizations and bodies.

Sectoral shifts in the economy of post-communist countries and countries with highly developed economies

The reflection of the qualitative development level of the economic system is carried out by covering the national economy's sectoral structure by the type of economic activity. An efficient sectoral structure of the economy should be consistent with a socially-oriented model of a market economy and be based on competitive advantages in the global division of labor and the economic advantages of international integration. An efficient sectoral structure of the economy thus guarantees the independence and dynamic development of any country (Bilotserkivets and Kryuchkova 2007).

The sectoral analysis of world GDP in general and in the chosen countries, in particular, allows us to note that the primary sector of the economy has 5.5% of the world's GDP structure. From 2001–2019, Romania has been the leader in the economy (2001 – 32.2%, 2019 – 21.2%), followed by Bulgaria (2001 – 25.8%, 2019 – 19.2%) and Ukraine (2001 – 20.3%, 2019 – 18.3%). At the same time, most countries with highly developed economies, except for Norway, had indicators of the primary sector of the economy in 2019 that fluctuated between 0.57% and 3.24%, showing a downward trend. The same indicators in Norway (2001 – 24.7%, 2019 – 17.7%) break the usual conclusions that the primary sector of the economy is most typical for countries with weak economies.

The secondary sector of the economy accounts for 27.9% of world GDP. This sector forms a major part of GDP, which develops areas such as defense, health, and education for improving society. However, this sector consumes energy and pollutes the environment the most. The leader in the secondary sector of the economy, according to the latest available data as of 2019, was held by China – 38.6% of GDP, followed by the Czech Republic – 30.7%, and Slovakia – 29.5%.

The tertiary, quaternary, and quinary sectors of the economy are the flagship of economic development, with 66.6% of world GDP. They are typical for developed countries, where time, knowledge, and potential are used to increase efficiency, productivity, and sustainability. Thus, in 2019, the share of services sectors in the GDP of highly developed countries that we studied fluctuated from 54.5% (China) to 87.8% (Luxembourg), with a tendency to constant growth. The service sector in all groups of countries (especially in the quaternary and quinary sectors of the economy) has growing against the background of a steady, albeit moderate in quantitative terms, trend of relative decline in the role of the industrial sector.

Ukraine has also demonstrated an impressive relative compression of the industrial sector (Heyets et al. 2011). It entered state independence and market transition with a relatively respectable industrial sector – 45% of GDP . However, it reduced industry's role in the economy, decreasing to 16.47%, the global average in 2019. The main result of transformational changes in Ukraine over the past two decades can be considered the formation of a multisectoral structure of the post-industrial economy with a respectable share of services in GDP (65.2%).

Our research considers it necessary to assess structural changes and differences to determine transformation processes in the previously defined economic systems. For this purpose, we can use some indices, particularly the Herfindahl-Hirschman index, the entropy index, the relative concentration index, the market share dispersion index, Gatev's integral coefficient of structural differences, and Salai and Ryabatsev's indices of structural shifts. They all have advantages and disadvantages. The Herfindahl-Hirschman index is traditionally used to measure business concentration in a particular market, but it is incomparable for structures with different elements. The entropy index is the inverse of the concentration (the higher its value, the lower the concentration of sellers in the market) but is used much less frequently. The dispersion of market shares is a rough analog of the indices mentioned above and is used as a supplementary method. There are no clearly defined boundaries to interpret the relative concentration index. The Gatev coefficient, the Salai index, and the Ryabtsev index are the most accurate and convenient tools for solving the goal defined in the study. They consider the size of the population, the number of groups, and the different contributions of those groups to the total volume of the studied feature (Kramarev 2017).

However, to assess further the significance of structural changes in the sectoral structure of national economic systems, we used the Ryabtsev index for several reasons. Firstly, the Salai and Gatev indices cannot be calculated if the share of the sector of the economy is zero. Secondly, the Ryabtsev index has a scale for assessing the significance of structural differences.

Empirical research of the structural changes in the sectoral structure for the periods 2001–2017 and 2001–2019 based on the Ryabtsev index allows us to conclude that there are structural changes in most national economic systems, which have to be studied (Table 1).

Table 1. The substantiality of structural differences by the Gross value added[2] of Ukraine and selected countries

Group	Country	Ryabtsev index 2001/2017	Ryabtsev index 2001/2019	Interpretation of the index
I	USA	0.047	0.051	An extremely low level of differences (0.031–0.070)
	Japan	0.035	0.099	
	Switzerland	0.050	0.029	
	France	0.054	0.058	
	Hungary	0.034	0.036	
	Slovakia	0.052	0.133	
	Australia	0.059	0.073	
	UK	0.067	0.060	
	Czech Republic	0.042	0.059	

2 Gross Value Added (GVA) provides a monetary value for the amount of goods and services that have been produced in a country, minus the cost of all inputs and raw materials that are directly attributable to that production.

Group	Country	Ryabtsev index 2001/2017	Ryabtsev index 2001/2019	Interpretation of the index
II	China	0.108	0.133	Low level of differences in structures (0.071–0.150)
	Luxembourg	0.080	0.077	
	Norway	0.101	0.116	
	Bulgaria	0.102	0.100	
	Ukraine	0.092	0.108	
	Belarus	0.132	0.293	
III	Romania	0.157	0.163	A significant level of differences (0.151–0.300)
	Russia	0.243	0.236	
	Georgia	0.199	0.302	
IV	Germany	0.021	0.013	Identity of structures (0.000–0.030)
	Poland	0.025	0.031	

Source: calculated and generated by the authors based on Data of Value added and its components for the period 2001–2019, available at OECD Statistics (n.d.); Eurostat (2019); State Statistics Service of Ukraine (2019); Federal State Statistics Service (2019); National Bureau of Statistics of China (2019); National Statistical Committee of the Republic of Belarus (2019); National Statistics Office of Georgia (2020).

According to the calculations given in Table 1, the most significant changes in the economy's sectoral structure by gross value added for the period 2001–2017 took place in Romania, Russia, and Georgia. During the period 2001–2019, Belarus joined these countries. At the same time, Ukraine is in the group of countries with a low level of structural differences, showing a tendency to grow the Ryabtsev index from 0.092 (2001–2017) to 0.108 (2001–2019).

The current structural transformation of highly developed countries economies is based on innovation and changing social needs through the priority development of those industries that determine the transition from an industrial to a post-industrial society. Accelerated development of the services sector and the relative reduction of the manufacturing sector's role have led to a gradual decline in employment in the secondary and a significant increase in the global economy's quaternary and quinary sectors. Moreover, it is characterized by the constant enrichment of new services. Thus, various national employment structures are formed to transfer workers from production branches to service sectors. In particular, highly developed countries, except China, created an "information" model of employment structure characterized by priority services. For example, in the USA, 80.49% of the economically active population worked in the service sector in 2019, in the UK – 83.52%, France – 81.17%, Luxembourg – 80.46%.

A more detailed analysis of Ukraine's distribution dynamics of employed population by economic sector from 2001 to 2019 showed a steady increase in the share of the employed population in the service sector from 52.91% to 62.8%. In general, the structure of the employed population by sector of the Ukrainian economy indicates the spread of the services sector in the system of social production, which fully reflects the trends of highly developed countries. By type of economic activity within

the services sector, almost 22.93% of employees worked in the areas of redistributing the value of GDP (wholesale and retail trade), 6.03% – in transport, warehousing, postal and courier activities, 5.9% – health care and the provision of social assistance. Education employed 8.4% of the economically active population aged 15–70 years. In addition, the number of people employed in information and telecommunications services in 2019 amounted to 1.7% of the services sector's total employment.

The Ryabtsev index determines the substantiality of structural changes in the sectoral structure of employment of the population of both groups of countries for the periods 2001–2017 and 2001–2019 (Table 2).

According to the calculations, most countries, including Ukraine, show a low difference in employment structure (Ryabtsev index 0.108 and 0.106 in 2001–2017 and 2001–2019, respectively). The most substantial changes in the sectoral employment structure occurred in Romania and China (the latest available data is for 2017). It is worth noting that Romania has also undergone a significant structural transformation in gross value added together with such countries as Georgia and Russia. At the same time, these countries showed a significant increase in GDP per capita. The most significant result can be observed in China, where GDP per capita increased over 7.32 times in 2001–2017 (latest available data), Romania – 7.67 times, Russia – 5.47 times, and Georgia – 5.86 times in 2001–2019.

Table 2. The substantiality of sectoral differences in the structure of employment in Ukraine and selected countries

Group	Country	Ryabtsev index 2001/2017	Ryabtsev index 2001/2019	Interpretation of the index
I	USA	0.053	0.058	An extremely low level of differences (0.031–0.070)
	Norway	0.042	0.053	
	Australia	0.065	0.072	
	Germany	0.068	0.061	
	France	0.050	0.049	
	UK	0.067	0.073	
	Slovakia	0.056	0.058	
	Czech Republic	0.038	0.046	
II	Japan	0.088	0.110	Low level of differences in structures (0.071–0.150)
	Luxembourg	0.105	0.110	
	Switzerland	0.093	0.089	
	Poland	0.115	0.125	
	Hungary	0.135	0.086	
	Bulgaria	0.084	0.105	
	Ukraine	0.108	0.106	
	Russia	0.120	0.147	
	Belarus	0.112	0.099	
	Georgia	0.137	0.405	

Group	Country	Ryabtsev index 2001/2017	Ryabtsev index 2001/2019	Interpretation of the index
III	Romania	0.238	0.195	A significant level of differences (0.151–0.300)
IV	China	0.614	–	A very significant level of differences in structures (0.501–0.700)

Source: calculated and generated by the authors based on Data of Labor input by activity for the period 2001–2019, available at OECD Statistics (n.d.); Eurostat (2019); State Statistics Service of Ukraine (2019); Federal State Statistics Service (2019); National Bureau of Statistics of China (2019); National Statistical Committee of the Republic of Belarus (2019); National Statistics Office of Georgia (2020).

Forecasting sectoral changes in post-communist economies and highly developed countries based on Markov chains theory

The theory of discrete Markov processes, i.e., Markov chains theory, was chosen as a mathematical tool for predicting structural changes (Meyn and Tweedie 2005). A random process with discrete states has a Markov property (aftereffect property) if, for any moment, the characteristics of the process are determined only by the state of the random process at a given time and do not depend on how the system behaved in the past.

Markov chain theory allows us to consider a change in the structure of a set as a stochastic process determined by two main characteristics: a stochastic vector of the initial state of a random process $X(t_0)$ and a stochastic matrix that determines the probability of process transition in one step $P=\left(P_{ij}, i, j=\overline{1,n}\right)$. Each element of this matrix P_{ij} is equal to the probability that in one step, the system will move from state S_i to state S_j. The order of the matrix n is equal to the number of states in which the system under study can be. The formula determines the probability of the system at time t in the appropriate form:

$$X(t)=X(t-1)\times P, \tag{1}$$

$X(t)=\left\{X_1^t, X_2^t, \ldots, X_j^t, \ldots, X_m^t\right\}$ – a vector that determines the probability of finding an object in the range of m states at time t; $X(t-1)$ is the corresponding probability vector for the previous step.

In the study of structural changes, the vectors' elements $X(t)$ and $X(t-1)$ were defined as relative values of the structure that reflect the nature of the distribution of objects by individual groups, namely the relevant sectors of the economy. If the structure of the phenomenon in the base period is known, it is necessary to predict the pop-

ulation's structure in subsequent periods. Thus, the main task of the theory is to estimate the transition matrix of the Markov chain.

1. The auxiliary matrix P' is formed, and the elements of the main diagonal are calculated by the formula:

$$P'_{ij} = \min\left\{S_i^0, S_i^1\right\},\ i = 1, \ldots, m. \tag{2}$$

where S_0, S_1 – are the vectors of the population structure in the previous and subsequent periods under the condition $\sum_{i=1}^{m} S_i^0 = \sum_{i=1}^{m} S_i^1 = 1$, while the elements remain unused of the previous structure of size $\Delta i = S_i^0 - P'_{ii}, i = 1, \ldots, m,$ and also elements of the following structure $\varepsilon_j = S_j^0 - P'_{jj}, i = 1, \ldots, m$. The distribution of Δi is made in proportion to the needs of columns ε_s, that is $P'_{ij} = \Delta i \frac{\varepsilon_j}{\sum_j \varepsilon_j}, i, j = 1, \ldots, m.$

2. The elements of the transition probability matrix are calculated:

$$P_{ij} = \frac{P'_{ij}}{S_i^0}, i, j = 1, \ldots, m. \tag{3}$$

The calculations that resulted from the forecast of sectoral shifts in the economies of Ukraine and the other selected countries by gross value added and employment for 2021 and for 2025 are presented in Tables 3–5. Given the forecast of sectoral shifts, we found the direction of the countries" socio-economic progress for the period 2001 to 2025.

The forecast data on the sectoral structure by the gross value added of highly developed countries, shown in Table 3, give grounds to expect the current structural change trends, significantly decreasing the pre-industrial sector's share while increasing its post-industrial sector. Simultaneously, for the period from 2001 to 2025, there is a growth of these countries" industrial economies. We assume that such trends are characteristic of increasing ICT development in production, leading to the reallocation of labor resources to other sectors due to the automation of easily algorithmic business processes, leading to increased ROI and increased investment attractiveness.

Ukraine, as well as most of the studied countries, is characterized by tendencies to increase the post-industrial sector while reducing the pre-industrial and industrial sectors of the economy for the period from 2019 to 2025 (Table 4). It indicates a progressive type of economic development.

Table 3. Forecast of sectoral changes of gross value added of highly developed countries

Sectoral structure, %		2001	2019	*change 01/19*	2021F	2025F	*change 19/25*	*change 01/25*
USA								
Pre-industrial sector	(S1)	2.45	2.48	*0.03*	2.52	2.58	*0.10*	*0.13*
Industrial sector	(S2)	19.16	15.65	*–3.51*	14.19	12.94	*–2.70*	*–6.22*
Post-industrial sector	(S3)	16.51	15.05	*3.48*	14.38	13.74	*1.34*	*4.82*
	(S4)	33.24	36.08		36.74	37.32		
	(S5)	28.65	30.74		31.53	32.16		
Norway								
Pre-industrial sector	(S1)	24.71	17.70	*–7.01*	15.14	13.24	*–4.46*	*–11.46*
Industrial sector	(S2)	14.20	13.75	*–0.45*	13.50	13.23	*–0.51*	*–0.96*
Post-industrial sector	(S3)	18.90	16.03	*7.46*	14.78	13.66	*4.97*	*12.43*
	(S4)	18.50	22.94		24.69	26.10		
	(S5)	23.69	29.58		31.89	33.77		
Luxembourg								
Pre-industrial sector	(S1)	1.12	0.58	*–0.54*	0.42	0.32	*–0.26*	*–0.80*
Industrial sector	(S2)	16.42	11.58	*–4.84*	9.96	9.01	*–2.57*	*–7.42*
Post-industrial sector	(S3)	16.76	14.74	*5.38*	13.82	12.96	*2.83*	*8.22*
	(S4)	45.84	46.43		46.25	45.74		
	(S5)	19.86	26.67		29.54	31.97		
Japan								
Pre-industrial sector	(S1)	1.49	1.01	*–0.48*	0.84	0.69	*–0.32*	*–0.80*
Industrial sector	(S2)	27.68	24.16	*–3.52*	22.58	21.11	*–3.06*	*–6.57*
Post-industrial sector	(S3)	21.59	19.69	*3.99*	18.81	18.00	*3.38*	*7.37*
	(S4)	24.39	21.69		20.50	19.47		
	(S5)	24.85	33.44		37.27	40.73		
China								
Pre-industrial sector	(S1)	14.20	6.90	*–7.30*	5.60	5.23	*–1.68*	*–12.92*
Industrial sector	(S2)	44.90	38.59	*–6.31*	35.84	33.42	*–5.17*	*–11.48*
Post-industrial sector	(S3)	16.60	16.90	*13.70*	16.85	16.72	*6.93*	*20.63*
	(S4)	8.90	16.50		20.79	24.13		
	(S5)	15.30	21.10		20.95	20.58		

Source: calculated and generated by the authors.

Table 4. Forecast of sectoral shifts by gross value added of the post-communist economies

Sectoral structure, %		2001	2019	*change 01/19*	2021F	2025F	*change 19/25*	*change 01/25*
Ukraine								
Pre-industrial sector	(S1)	20.26	18.37	*–1.89*	17.52	17.15	*–1.22*	*–3.11*
Industrial sector	(S2)	22.63	16.47	*–6.16*	14.06	12.02	*–4.45*	*–10.61*
Post-industrial sector	(S3)	29.03	26.96	*8.04*	25.99	25.09	*5.68*	*13.72*
	(S4)	13.68	18.67		20.71	22.27		
	(S5)	14.40	19.53		21.71	23.47		

Sectoral structure, %		2001	2019	*change 01/19*	2021F	2025F	*change 19/25*	*change 01/25*
Hungary								
Pre-industrial sector	(S1)	5.93	4.34	*–1.59*	3.81	3.56	*–0.77*	*–2.37*
Industrial sector	(S2)	27.60	26.39	*–1.21*	25.81	25.30	*–1.09*	*–2.29*
Post-industrial sector	(S3)	19.53	18.92	*2.80*	18.61	18.29	*1.86*	*4.67*
	(S4)	23.30	25.96		27.04	27.85		
	(S5)	23.65	24.40		24.72	24.99		
Czech Republic								
Pre-industrial sector	(S1)	4.83	2.75	*–2.08*	2.11	1.68	*–1.07*	*–3.16*
Industrial sector	(S2)	31.91	30.67	*–1.24*	30.07	29.49	*–1.18*	*–2.42*
Post-industrial sector	(S3)	22.91	20.10	*3.32*	18.83	17.65	*2.26*	*5.58*
	(S4)	21.24	24.75		26.17	27.40		
	(S5)	19.10	20.76		22.81	23.78		

Source: calculated and generated by the authors.

According to Furastier, the profound modification of the sectoral structure of employment is due to the dominance of the consumption factor, which explains the significant growth of the tertiary, quaternary, and quinary sectors in the "service society". This society's optimal structure (Krasil'nikov 2005) can be achieved when about 85% of the employed population will be in these sectors, 10% in the secondary, and 5% in the primary.

Table 5. Forecast of sectoral changes in the employment of highly developed and post-communist economies, %

Country	S1			S2			S3+S4+S5		
	2001	2019	2025	2001	2019	2025	2001	2019	2025
Ukraine	20.77	18.10	16.38	26.32	19.10	13.89	52.91	62.80	69.73
Hungary	7.15	4.27	2.76	30.83	26.59	23.18	62.03	69.14	74.06
Czech Republic	5.89	3.67	2.42	35.82	33.99	32.28	58.28	62.34	65.29
Japan	5.83	3.83	2.52	27.88	22.74	18.77	66.29	73.43	78.71
China	53.19	4.03	1.40	50.85	41.25	43.80	28.17	54.72	54.25
Norway	5.74	4.55	3.61	17.17	16.46	15.79	77.09	78.98	80.58
USA	2.53	2.50	2.46	20.56	17.00	14.47	76.90	80.50	82.98
Luxembourg	3.24	2.09	1.35	23.16	17.60	13.37	73.61	80.31	85.28
Optimal	5			10			85		

Source: calculated and generated by the authors.

Trends in sectoral employment changes are similar for both highly developed countries and those with economies in transformation. They are characterized by a decrease in the share of employment in the economy's primary and secondary sectors, and an increase in the share of employment in the service sectors (tertiary, quaternary, and quinary). As it can be seen from Table 3, Luxembourg, the USA, and Norway are among the countries which are the closest to the optimal "consumer society" employment structure in 2025.

Digital transformation as a factor in changing the sectoral structure of the economy

Digital transformation is exceptional in its speed and scale, which calls into question traditional thinking about the most effective way of organizing economic and social activities. The Internet and public platforms are able to provide a wide range of networking activities that serve common interests. As a result, markets, non-market transactions, and interactions between people are gaining new scale. Instead of a binary choice between public and private, digitalization involves gradations, hybrids, and options. In contrast to the stable and embedded architectures of the physical world or, in this regard, the developed institutions of advanced economies, digital transformation makes it possible to continuously fine-tune access, control, participation, and functioning.

According to the transformational concept of transition states, the nature of digital transformation processes, which acts as a qualitative leap or a civilizational shift, interrupts the slow evolutionary development. Researchers pay attention to the emergence of so-called bifurcation points (changes), suggesting branching and the emergence of alternative pathways. This tendency, discovered by Bell (1973), significantly enriches and deepens Marx's single-line determinism theory. Given its findings, multiline determinism provides a multi-vector principle of transformation that involves the critical factors of technology, property, politics, and culture. All of them are of great value as an independent factor of determinism.

The state of transition involves extraordinary contradictions, which affect the struggle of old and new phenomena. This pattern is determined by when the "victory" of new elements over "old" occurs, transforming a mixed transitional and unstable state into a new, organically stable system, which then becomes stable. There are trends in new quality development during this period, which are differently refracted in national economies, depending on each country's position in the world classification.

The transformation process ends with the transition to a new qualitative development stage, which sooner or later affects all countries. It usually begins in developed countries. The reason for the economic system's transformation is that it creates living conditions for the population with such a volume and structure of social production that domestic needs are met. Economists have always focused on general theoretical and practical problems of consumption: the place of consumption in social reproduction, the relationship with social production, the impact of consumption on social reproduction, factors of change, nature, the features and scale of consumption, and consumer behavior.

The digital transformation of the economy occurs in waves, in line with technological progress and the spread of innovation. The first wave of digital transformation is related to introducing and integrating those technologies that are now considered "mature". Such technologies include management information systems that automate data processing used to monitor and report on the results of the object of management.

They also include telecommunication technologies, particularly broadband (stationary, mobile) and voice telecommunications (stationary, mobile), which provide remote access to information.

The second wave of digital transformation determines the spread of the Internet and its respective platforms (search engines, markets), which allow businesses and consumers to interact in the delivery and distribution of products. Finally, the third wave is characterized by the development of advanced technologies, such as big data analytics, the Internet of Things, robotics, sensors, and artificial intelligence. They were designed to improve information processing and decision-making, and to automatize easy-to-algorithm tasks for businesses and governments. These newest technologies are usually not considered separately but are integrated into the mature technologies of the first and second waves.

Each wave of digital transformation has a set of social and economic consequences. Thus, technological innovations of the first wave, such as computers, broadband access, and mobile communications, began their formation between 1950 and 1975. The development of these technologies occurred between 1960 and 2000, and the socio-economic consequences became evident between 1990 and 2010. Second-wave technological innovations, such as Internet platforms and cloud computing, began their formation rapidly between 1970 and 1990, and development in 1995. It continues today. The first socio-economic effects began to emerge in 2005 and continue to this day (Katz 2017). Technological innovations of the third wave, particularly the Internet of Things, robotics, artificial intelligence, and machine learning, began their formation in 1980. Their usage dates back to 2010, and their socio-economic consequences should be expected no earlier than 2020. Thus, given that none of the processes is yet complete and in their infancy, the study of economic and social impacts may or may not be supported by forecasts based on past impacts.

The most apparent result of these three waves of digitalization is the development of the digital economy. According to Schwab (2016), the digital economy is an innovative, dynamic economy based on the active introduction of information and communication technologies in all economic activities and spheres of society. A characteristic feature of the digital economy is its connection with the on-demand economy, which involves not selling goods and services but gaining access to them when needed. Moreover, orders are received online and executed offline. The advantages of on-demand economics include the high speed of obtaining the necessary service or product, lower costs for consumers by reducing the number of intermediaries, and simplified access for suppliers of goods and services to users.

The International Organization for Economic Cooperation and Development (OECD) and scientist Thomas Massenburg have identified three main components of the digital economy:

1. Fundamental innovations (semiconductors, microprocessors), essential technologies (computers, telecommunications devices) and stimulating infrastructure (Internet and telecommunications networks);

2. Digital and information technology services based on raw digital technologies, including digital platforms, mobile applications and electronic payment systems;
3. The digital economy includes a broad range of activities where digital products and services are used, particularly e-commerce. This digital economy component should also include new activities or business models which are transformed due to digital technologies (Bukht and Heeks 2017).

These features distinguish the digital economy from previous stages of economic development and society and the digital sector from other sectors and industries of the modern economy where there are specific, unique laws. These unique laws include the law of network effect (Metcalfe's law) and the law of reverse pricing (Hilder's law). In the initial stages of the development of the digital economy, the improvements in machinery, technology, and the quality of products were invariably accompanied by a rise in price and a relative decrease in profit.

Hilder suggested, and empirical research confirmed that as computer capacity increases, expands, and improves network structures, there is an absolute and relative decrease in prices for information and communication technologies. The same decrease per unit of information is close to zero. According to the network effect, the value of networks for users depends on their number. As the participants of the network interact exponentially, a synergistic effect begins. It is expressed in improving customer service, increasing access to a variety of information, and expanding spatial boundaries. The result is that geographical remoteness loses its significance.

In view of the structural changes in the world economy, which is characterized as post-industrial, it is essential to assess the extent of digital transformation (Pohl and Santarius 2020). It is worth noting that information and communication technologies become an essential component of the methodology of global indexes. Such global indexes include the knowledge economy index, the Global Competitiveness Index, the Global Competitiveness Index 4.0, the Innovation Development Index, the Information and Communication Technology Development Index, the Digital Economy and Society Index, the Digital Evolution Index (Chakravorti and Chaturvedi 2017), the World Digital Competitiveness Index, the Network Readiness Index, and the BCG[3] e-Intensity index representing the level of digitalization of the economy. Therefore, a review of the last aspect allows us to identify three long-term trends in global ICT development.

The first is the increasing availability of communication services in general. A decade after the World Summit on the Information Society (WSIS) in 2005, there was a rise in mobile cellular telephony, leading to its almost complete penetration in developed and developing countries.

The second long-term trend is the growth of broadband services with a speed of 256 Kbps and above. From 2007 to 2019, subscriptions to fixed broadband networks in-

3 BCG – Boston Consulting Group.

creased by 183%. In addition, active mobile broadband subscriptions grew extremely fast, from 4.0 subscriptions per 100 population in 2007 to approximately 56.4 per 100 people in 2019. Available bandwidth has also increased rapidly, especially in developed countries. This growth in broadband has led to much wider and more efficient usage of the Internet and growth in advanced services.

The third trend is the predominance of mobile services over landlines. Today, mobile cellular subscriptions make up more than 90% of voice subscriptions, and in the least developed countries – more than 98%. The number of landline subscriptions has been steadily declining in recent years as a growing number of people have opted for mobile and landline access. Mobile subscriptions also dominate the broadband market, accounting for just over 80% of broadband subscriptions worldwide (although this was accompanied by an increase in fixed broadband penetration).

But the key question we need to answer in this section is whether digitalization actually leads to the development of the service economy. The contribution of the ICT sector to this development differs between countries. Manufacturing grows fast in China's ICT sector. At the same time, in other countries such as Switzerland, Norway, or Russia (Suslov 2019), the value added from ICT goods has remained roughly constant while the value added in ICT services has risen (Eurostat 2019). One possible reason for this difference is the relocation of manufacturing, for example, to China (OECD 2019).

If we look at the share of ICT services in the overall ICT sector, they made up the lion's share in 2014, with 73.1% compared to 26.9% of ICT manufacturing (Lange et al. 2020). More importantly, its share rose in basically all selected countries with data available from 2001 to 2017.

Therefore, the development within the ICT sector fosters the development of the service economy. However, this does not conclusively ascertain whether digitalization also fosters tertiarization in the rest of the economy.

Interconnection between digital transformation and sectoral changes in the economy

An essential step in this study is to determine the degree of impact of digital transformation on structural changes in the economy. We used the classical Spearman rank correlation coefficient and Kendall coefficient.

The correlation is determined based on empirical data such as the Ryabtsev's index on gross value added and employment (Table 2–3), as well as the ICT Development Index developed by the International Telecommunication Union (ITU), which is a measure of the country's economic readiness for digital transformation (Figure 1).

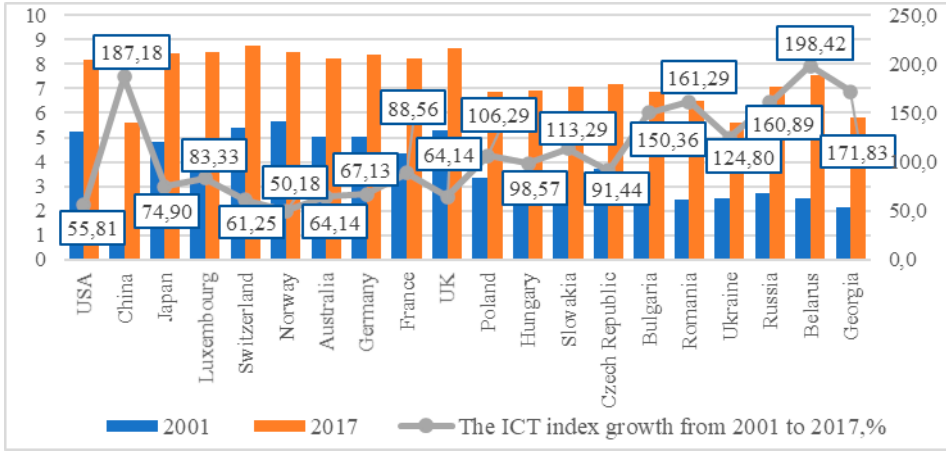


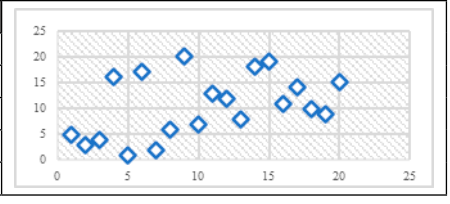
Figure 1. The ICT index growth of selected countries for the period from 2001 to 2017
Source: calculated and generated by the authors based on *Measuring the Information Society Report* 2017.

The choice of the ICT Development Index (IDI) is because, unlike other indices, the way it is calculated did not change during the study period.

The ratio between the data sets of Ryabtsev's index in terms of gross value added and the increase in ICT development with data available from 2001 to 2017 determined based on Spearman's and Kendall's coefficients is not statistically significant (Table 6).

Table 6. Correlation coefficients and criteria of their significance for a pair of values: Ryabtsev index on gross value added; ICT index growth, %

Values of coefficients	
The Spearman's rank coefficient	0,44
The Critical Point of the Student's-t	*0,52*
The Kendall rank correlation coefficient	0,31
The critical point of the Laplace function	*0,32*
Observations	20



Source: calculated and generated by the authors.

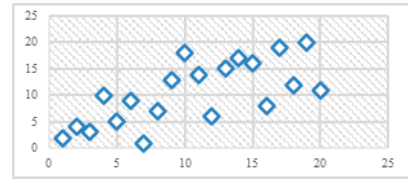
Such conclusions are based on the reliability of Spearman's and Kendall's rank correlation coefficients (Valz's and Thompson 1994; Gaißer and Schmid 2010), which was performed using the Student's t-test at the number of degrees of freedom n–2 = 18 and the critical point of the Laplace function. However, if we calculate the Spearman coefficient for the group of post-communist countries, we get p = 0.84 (for the critical point, p = 0.52). It indicates a high degree of closeness of the relationship (on the Chaddock scale) between the studied data sets. A similar conclusion can be made based on calculating the Kendall coefficient, where the value of the indicator is $\tau = 0.64$ (for critical point $\tau = 0.49$). This allows us to conclude that the greater the growth

of the ICT index for the period 2001–2017, the more significant the structural shifts in gross value added for this group of countries.

The closest interconnection, which confirms the Spearman and Kendall criteria, is between the data of the Ryabtsev index on the level of employment and the growth of the ICT development index (Table 7). It follows that ICT development has a more significant impact on the structure of employment than on the structure of value-added, which is fair, as digital technologies lead to a redistribution of labor from the primary and secondary sectors to services.

Table 7. Correlation coefficients and criteria of their significance for a pair of values: Ryabtsev index by employment; ICT index growth, %

Values of coefficients	
The Spearman's rank coefficient	0,69
The Critical Point of the Student's-t	*0,42*
The Kendall rank correlation coefficient	0,53
The critical point of the Laplace function	*0,32*
Observations	20

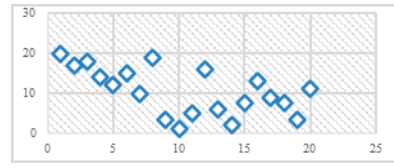


Source: calculated and generated by the authors.

It is interesting to study the interconnection between the Ryabtsev index by employment rate and the ICT index as of 2017. Calculations obtained in Excel demonstrate a statistically significant interconnection between this pair of values, and the value of the Spearman coefficient is equal to –0.57 (Table 8).

Table 8. Correlation coefficients and criteria of their significance for a pair of values: Ryabtsev index by employment; ICT Development Index, 2017

Values of coefficients	
The Spearman's rank coefficient	–0,57
The Critical Point of the Student's-t	*0,47*
The Kendall rank correlation coefficient	–0,37
The critical point of the Laplace function	*0,32*
Observations	20



Source: calculated and generated by the authors.

Evaluating the reliability of the rank correlation coefficient, which was performed using the Student's t-test criterion at the number of degrees of freedom n–2 = 18, found the coefficient to be reliable. A negative Spearman value indicates the direction of the relationship between the variables. Less significant structural changes are characteristic of countries with a high ICT development index.

Basic sectoral model of the economy in terms of digital transformation

Forecast data on the sectoral structure of gross value added give grounds to expect the continuation of existing trends in structural changes. Significantly reducing the share of the pre-industrial sector while increasing it in the post-industrial sector generally indicates progressive economic development in most countries except Ukraine. Trends in sectoral employment are similar both for highly developed countries and countries with economies in transformation. However, only highly developed countries will have a structure close to the optimal employment structure in Forestier's "consumer society" in 2025.

The empirical evidence discussed earlier highlights the relationship between digital transformation and sectoral shifts in the economy. On the one hand, the calculations indicate the extremely low significance of the interconnection between digital transformation and sectoral changes in gross value added. On the other hand, this relationship is significant between digital transformation and sectoral changes in employment. Moreover, the relationship between the Ryabtsev Index and the ICT Development Index as of 2017 is evidence that if the level of ICT development (post-communist countries and communist China, which was included in the group of highly developed countries as one of the leaders the world's largest GDP) is lower, the sectoral changes in the structure of employment are more significant. All this suggests that the digital transformation does not directly but indirectly affect the change in the sectoral structure of the economy through the redistribution of labor resources and productivity growth due to the widespread use of ICT technologies.

However, it can be assumed that the low correlation between these variables is a consequence of the inconsistency of the modern five-sector model of the economy with the conditions of widespread digital transformation, where the reflection of the digital economy is fragmentary. The modern basic model based on existing standards of economic sectoral classification considers, on the one hand, fundamental information technologies and stimulating infrastructure (the core of the digital economy), and on the other, the digital economy. It embidies the formation of new business models that are transformed by digital technologies in all sectors of the economy, without exception.

However, this model does not fully reflect the range of services based on basic digital technologies (including digital platforms, mobile applications, and electronic payment systems) and a wide range of new activities using digital goods and services.

Given the above, it is important to transform the basic sectoral model of the economy, which reflects the development of the digital economy. The author's vision of such a model is shown in Figure 2.

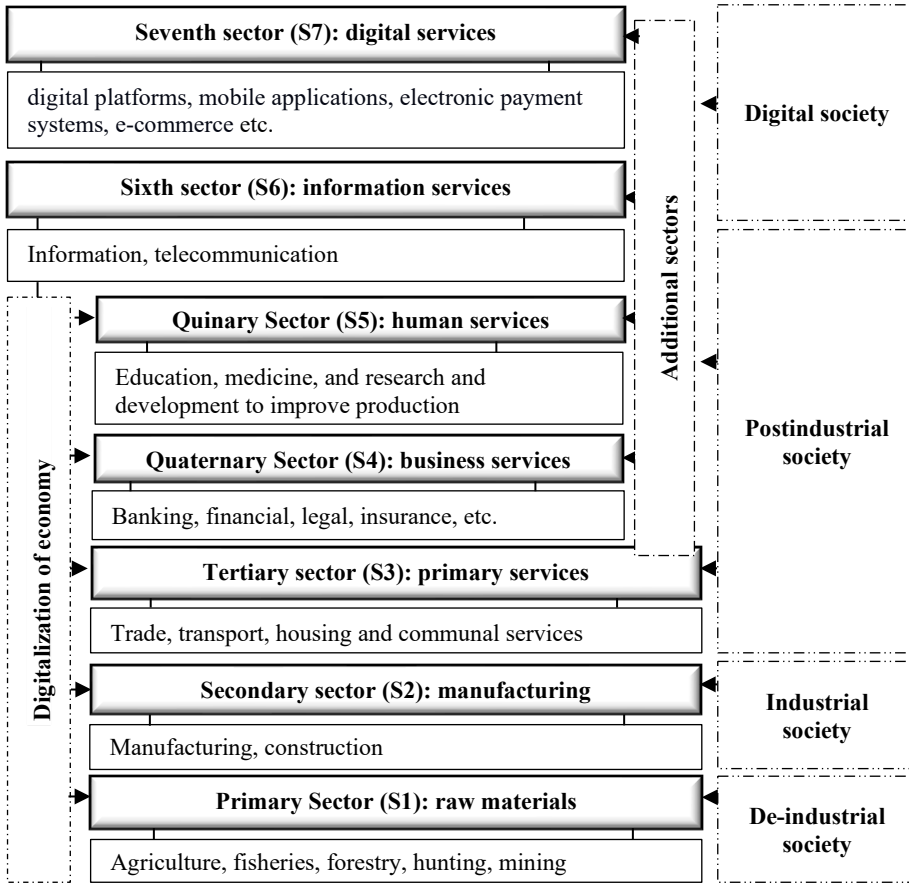


Figure 2. Basic sectoral model of the national economy in terms of digital transformation
Source: generated by the authors.

The improved structural and logical scheme of the economy's basic sectoral model considers the digital economy's wave-like development as the most obvious result of the digital transformation. This approach allows us to assess the qualitative level of its development from the standpoint of the consequences of digital transformation based on the decomposition of the economy.

Conclusion

The purpose of this article was to explore the impact of digital transformation on structural changes and differences of sectoral models of the economy of Ukraine, other post-communist countries, and countries with highly developed economies. We as-

sumed that the significance of sectoral changes in the economy depends on the level of digital transformation. To confirm the scientific hypothesis:

1. The sectoral structure of Ukraine's economy was analyzed in terms of gross value added and employment in comparison with other countries, which were conditionally divided into two groups: highly developed and post-communist countries.
2. Using the Ryabtsev index, the significance of structural changes in gross value added and employment for the period 2001–2019 was determined.
3. The forecast data of the sectoral structure of airborne forces and employment of Ukraine and other countries subject to research were determined, which allowed us to identify the type of economic development (progressive or regressive).
4. To determine the position of Ukraine in the world economic system, indices such as the index of the knowledge economy, the global competitiveness index, and the index of innovative development were analyzed, where information and communication technologies (ICT) became an important component of the study. At the same time, Ukraine was assessed through the prism of indices for measuring digital development, in particular, the ICT development index, the network readiness index, and the global digital competitiveness index. However, the dynamic analysis of most interstate indices was limited due to changes in the system of indicators and periods of their evaluation and research. The only index whose methodology did not change between 2001 and 2017 was the ICT development index, which was used in further research.
5. Based on the Ryabtsev index on gross value added and employment and the growth of the ICT development index for the period 2001–2017, using Spearman's and Kendall's rankings, it was found that ICT development has a significant impact only on changes in the employment structure. In general, the research results indicate the indirect effect of digital transformation on the significance of structural changes in gross value added through redistribution of labor resources and labor productivity, which only partially confirms the previously defined hypothesis. However, it can be assumed that the low correlation between variables is a consequence of the inconsistency of the five-sector model of the economy with modern development realities, and therefore it needs some transformations.

However, this study is not without limitations. The main limitation is the small sample size and the method of selecting and assigning countries to a particular group. For example, classifying China as a highly developed country by only one criterion is not justified. Because China's data do not match the averages in selected countries, they are often in the statistical release zone, which worsens the key parameters of regression-correlation analysis.

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Wpływ cyfryzacji na zmianę struktury sektorowej gospodarki: analiza porównawcza Ukrainy i wybranych krajów

Artykuł analizuje wpływ transformacji cyfrowej na zmiany w strukturze sektorowej gospodarki Ukrainy, innych krajów postkomunistycznych oraz krajów o gospodarkach wysoko rozwiniętych. Po pierwsze, oszacowano wielkość zmian strukturalnych i różnice w modelu sektorowym według wartości dodanej brutto i sektorowego modelu zatrudnienia według kraju przy użyciu wskaźnika Riabcewa. Po drugie, opracowano prognozę zmian w strukturach sektorowych badanych gospodarek na lata 2021 i 2025 wykorzystując dyskretne procesy Markowa. Prognozy pozwoliły określić kierunek

postępu społeczno-gospodarczego krajów wysoko rozwiniętych i postkomunistycznych. Po trzecie, zakładając, że rozwój technologii ICT spowodował zidentyfikowane w wyniku oceny zmiany sektorowe, przeanalizowano dostępne oceny poziomu transformacji cyfrowej wybranych gospodarek i przedstawiono światowe trendy w ICT. Wreszcie, określono wpływ indeksu ICT na istotność zmian sektorowych w gospodarkach krajów postkomunistycznych oraz krajów o gospodarkach wysoko rozwiniętych. Wyniki badania pozwoliły na stwierdzenie, że rozwój technologii cyfrowych wpływa pośrednio na zmiany strukturalne gospodarki poprzez realokację zasobów pracy z jednego sektora do drugiego. Artykuł uzasadnia potrzebę doskonalenia modelu sektorowego gospodarki poprzez dodanie branż związanych wyłącznie z gospodarką cyfrową.

Słowa kluczowe: struktura sektorowa etsonomii, transformacja cyfrowa, łańcuchy Markowa, wartość dodana brutto, struktura sektorowa wdrożenia

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