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QUALITY MANAGEMENT IN INDUSTRY 4.0 THROUGH THE MOVEMENT OF LABOR RESOURCES TOWARDS THE "CORE" OF THE DIGITAL ECONOMY

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A B S T R A C T

The purpose of the article is to develop a scientific and practical approach to quality management in industry 4.0 through the movement of labor resources towards the "core" of the digital economy. For the most complete coverage of the digital era, the study was conducted in 2017-2022 based on the experience of 72 countries covered by digital competitiveness statistics that is, representing the global "core" of the digital economy. The article defines the impact of the movement of labor resources towards the "core" of the digital economy on quality in industry 4.0 using the regression analysis method. The authors present forecasts for the "Decade of Action" that reveal the prospects for improving quality in industry 4.0 through optimizing the movement of labor resources towards the "core" of the digital economy. As a result, the article proposes a promising mechanism for quality management in industry 4.0 through the movement of labor resources towards the "core" of the digital economy. This mechanism contains framework recommendations for improving quality management through the regulation of migration flow and HRM in Industry 4.0. The originality of the article lies in the fact that it forms a new vision of the process of labor movement to the global "core", taking into account the specifics of industry 4.0, which for the first time makes it possible to study it from the point of view of its impact on quality (and not quantity – as it was during the first three industrial revolutions) in industrial production, which defines the uniqueness of the Fourth Industrial Revolution. The theoretical significance is that the article has clarified the specifics of the movement of labor resources towards the global "core" in the digital economy from the standpoint of quality in industry 4.0. Migration policy implication is related to the fact that the author's recommendations will ensure an increase in the effectiveness of this policy by optimizing the flow of labor resources towards the global "core.

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1. INTRODUCTION

Industry 4.0 is a special area of the digital economy, fundamentally different from other areas in terms of quality for two reasons. Firstly, product quality is of paramount importance in Industry 4.0. In case of non-compliance with the current quality standards, the products of industry 4.0 are defective and unsuitable for practical use. Therefore, unlike other sectors of the economy, the production of products of inappropriate quality does not make sense, since it is unprofitable. Therefore, quality management is the central and most important management process in industry 4.0.

Secondly, unlike other technically complicated spheres, the role of human resources in ensuring high quality products in industry 4.0 is more complex. The high level of automation of economic processes characteristic of industry 4.0 reduces its quantitative need for human resources, but at the same time increases the requirements for their quality – the level of qualification, the degree of digital competencies and creative activity. In order to fully and efficiently meet the needs of industry 4.0 in human resources, it is insufficient to eliminate the shortage of highly qualified human resources in the labor market (which is sufficient for other areas).

It is also necessary to have a fairly high level of competition among highly qualified human resources in the labor market in order to generate market incentives for the increment of human potential through lifelong learning; to ensure the high value of employment by profession, which contributes to the retention of the best personnel in the workplace; to encourage the personnel involved in the production process for the fullest disclosure of their human potential – strict compliance with quality standards, the fullest use of digital competencies, as well as the manifestation of the highest possible innovative activity.

These reasons cause a significant dependence of quality management in industry 4.0 on the labor market situation, which is determined by a number of factors. Among these factors, studied in detail in the existing literature, are the development of science and higher education for the creation of industry 4.0 technologies and the training of digital personnel; state regulation of the labor market; automation, leading to the release of personnel and the need for retraining. Due to the fact that the migration factor is little studied, and at the same time has a serious impact on market conditions, it deserves special attention.

When studying migration processes in the world economic system, it is advisable to rely on the concept of its structure, according to which a global "core" and a global "periphery" are distinguished (Glass and Cruz, 2023). The advantage of this concept in the context of the Fourth Industrial Revolution in comparison with alternative classifications of countries is that it makes it possible to define accurately and reliably the boundaries of the leading digital economies. Thus, the countries participating in the IMD World Competitiveness ranking (2023) and demonstrating the highest global digital competitiveness include both developed and developing countries, have different income levels, demonstrate different rates of economic growth, and their list covers all geographical regions of the world.

Therefore, it is most correct from a scientific point of view to designate the world's leading digital economies as the global "core" of the digital economy (Mervar and Jokić, 2022, Arsovski 2023). The global "periphery" in this article refers to a set of countries with emerging or developing digital economies: not covered by the IMD (2023) statistical data (Chiba, 2020). They are opposed to the global "core" of the digital economy, interpreted as a set of countries with high competitiveness of the digital economy (covered by IMD statistics (2023)), specializing in knowledge-intensive and high-tech industries, actively engaged in high-tech export and occupying leadership positions in global high-tech markets (Santarelli et al., 2023).

The traditional and historically continuous movement of labor resources from the global "periphery" towards the global "core" needs to be rethought in the context of the Fourth Industrial Revolution, as it causes uncertain implications for quality in industry 4.0. This determined the purpose of this study, which is to develop a scientific and practical approach to quality management in industry 4.0 through the movement of labor resources towards the "core" of the digital economy.

This purpose is achieved by solving the following tasks. The first task is to determine the impact of the movement of labor resources towards the "core" of the digital economy on quality in industry 4.0. The second task is related to identifying the prospects for improving quality in industry 4.0 through optimizing the movement of labor resources towards the "core" of the digital economy. The third task is to create a promising quality management mechanism in industry 4.0 through the movement of labor resources towards the "core" of the digital economy.

The originality of this article lies in the fact that it has formed a new vision of the process of labor movement towards the global "core" that takes into account the specifics of industry 4.0 and focuses for the first time on the consequences for quality (and not quantity – as it was during the first three industrial revolutions) in industrial production, which determines the uniqueness of the Fourth Industrial Revolution.

The theoretical significance of the authors' vision lies in the fact that it reflects and takes into account the relationship between SDG5 (ensuring gender equality among digital personnel), SDG10 (guaranteeing social

justice in the segment of highly qualified personnel in the labor market), SDG8 and SDG9 (ensuring decent employment for digital personnel, creating knowledge-intensive jobs to unlock human potential in industry 4.0), SDG16 (improving the efficiency of the migration institute) and SDG17 (international partnership on migration), and also opens up the possibility for their systematic implementation through the management of the movement of labor resources towards the global "core".

2. LITERATURE REVIEW AND GAP ANALYSIS

2.1. The essence of the process of the movement of labor resources towards the global "core" in the pre-digital era

The fundamental basis of this research is the scientific provisions of the concept of labor migration. This concept indicates the importance of human resources for industrial and manufacturing engineering – based on the experience of the first three industrial revolutions. The concept under consideration also demonstrates the need to take into account the migration influx of human resources in management information systems for full-scale and highly effective information support for human resource management (HRM) of industrial enterprises.

In this study, the movement of labor resources towards the global "core", taking into account the context of industrial revolutions, is interpreted as the flow of the most mobile human resources in the process of labor migration into economies with the largest and most dynamically developing industrial production (Amrin et al., 2020; Zinatsa and Saurombe, 2022).

This is a natural process of balancing the labor market, in which ambitious foreign labor resources satisfy the industrial and manufacturing needs of industries (de Lange, 2020; Matkovskaya et al., 2022). The concept in question was formed during the first three industrial revolutions and characterizes the pre-digital era.

According to this concept, low-skilled labor resources prevailed in the composition of the workforce moving towards the global "core" in the pre-digital era. They satisfied the growing need of industrial and manufacturing companies for cheap human resources (Popkova, 2021). The combination of one's own motivation (the desire to stay in the workplace and increase one's labor income) and managerial incentives (labor rationing, awards for an overfulfillment of labor norms, piecework form of payment) made it possible to achieve high labor productivity (Chan, 2014).

All this contributed to an increase in the volume of industrial and manufacturing production. Nevertheless, low-skilled foreign personnel did not satisfy the economy's need for human resources to improve quality, since, on the one hand, they did not have the necessary competencies and, on the other hand, they were programmed to improve quantitative labor indicators, but not qualitative ones (King, 2022).

The power of foreign personnel in the labor market of the global "core" from the standpoint of quality was low due to ignorance of quality standards and a lack of competencies to comply with them (Jacobs, 2019). Therefore, migrant workers were attracted to jobs with a high intensity of physical labor, but at the same time with a low intensity of intellectual labor (Finnsdottir, 2019). Due to the low power in the labor market, foreign cadres agreed to the conditions offered by employers, which, as a rule, did not ensure the development and disclosure of their human potential (Chan, 2019).

The conditions attracting labor resources to the global "core" were associated with a higher quality of life (than in the global "periphery") (Bisho and Sam, 2022). That is, labor migrants were more concerned with the benefits that were not directly related to professional activity than in the disclosure of their human potential (Popkova, 2023). Because of this, the social and labor elevators created by migration assumed a low willingness of labor migrants to contribute to quality improvement. This limited their value for industrial and manufacturing engineering and assumed the continued reliance on irreplaceable local highly qualified personnel in the quality management of industrial products (Amit and Chachashvili-Bolotin, 2018).

The consequences of the influx of foreign labor resources for the economy of the global "core" in the pre-digital era were associated with overcoming the shortage in the labor market in the segment of low-skilled personnel, with a fuller utilization of production capacity and quantitative increase in production (Jakobson and Kalev, 2020). In other words, there was an acceleration of industrial and manufacturing economic growth (Yu et al., 2022). At the same time, the high quality of industrial products was achieved at the expense of local highly qualified personnel (Liu, 2022). (Liu, 2022).

2.2. Digital economy as a new global landscape transforming quality management processes in industry 4.0 and the movement of labor resources towards the "core"

The Fourth Industrial Revolution has led to the emergence of the digital economy as a new global landscape. In this digital landscape, the level and pace of industrial development of the economy have been replaced by a new criterion for distinguishing the global "periphery" and the global "core" – the level of development of industry 4.0, as well as the pace of its high-tech economic growth and export (Popkova

and Sergi, 2022; Sergi and Popkova, 2022). The existing concept of labor migration does not fully take into account the specifics of the digital context, which is its disadvantage.

The noted disadvantage indicates a gap in the literature associated with the uncertainty of the implications of the movement of labor resources towards the "core" of the digital economy for the quality of products in industry 4.0. This article seeks to fill the identified gap in the literature and poses the following two research questions. *RQ_1: What are the implications of the movement of labor resources towards the "core" of the digital economy for product quality in industry 4.0?* In the existing scientific literature covering the experience of industrial and manufacturing engineering in the digital age, the following manifestations of quality in industry 4.0 are highlighted, which are directly related to the human resources:

- Digital (technological) competencies of human resources used in industrial and manufacturing engineering. The higher the level of digital competence and knowledge of the practical features of technological processes and quality standards of high-tech production, the higher the quality of products in industry 4.0 (Jumambayev et al., 2018);
- The activity of using big data (including through ubiquitous computing, UC, and IoT) and their "smart" analytics using artificial intelligence (AI) (Yüksel and Ersöz, 2023). The higher the level of qualification of digital personnel, the more actively they are able to master and use these technologies more effectively to improve product quality in industry 4.0 (Kondrashov et al., 2023). Advanced decision-making automation tools are at the heart of industrial and manufacturing engineering in industry 4.0 and allow for improved quality control and certification of high-tech industrial products;
- The level and pace of digital transformation and digital competitiveness of industrial enterprises in industry 4.0. The higher the level of qualification of digital personnel, the more actively they are able to master and more effectively use advanced industrial automation technologies, in particular robots. Advanced means of automation of the production process are critically important for industrial and manufacturing engineering in industry 4.0, as they allow producing more complex products, reducing the share of defects, as well as increasing production volume with consistently high product quality (Matytsin and Rusakova, 2021);
- The strength of global brands of products in industry 4.0, largely determined by the quality of these products (Denisov et al., 2018). The skill level of digital personnel, as well as corporate social responsibility and the creation of "green" jobs largely determine the product quality of Industry 4.0 and the strength of its global brands (Bazrkar et al., 2022; Cardoso et al., 2022; Sozinova and Saveleva, 2022).

Based on the works of Dyakov et al. (2022), Popkova (2022), which note the advantages of labor migration in the digital age as a potential answer to the above RQ_1, the following hypothesis is put forward in this article. *H_1*: the movement of labor resources towards the "core" of the digital economy contributes to improving the quality of products in industry 4.0 through: 1) development of digital (technological) competencies of human resources used in industrial and manufacturing engineering; 2) increasing the activity of using Big data and its "smart" analytics based on artificial intelligence (AI) for intelligent decision support for quality management in industry 4.0; 3) increasing the level and pace of digital transformation and digital competitiveness of industrial enterprises in industry 4.0; 4) strengthening the power of global brands of products in industry 4.0.

The article also raises another research question. *RQ_2: What conditions in industry 4.0 determine the movement of labor resources towards the "core" of the digital economy?* While the standard of living remains a significant condition determining the movement of the international migration flow, it seems that in the digital age this condition ceases to be the only one and fades into the background. Based on the works of Andronova and Ryazantsev (2023), Galos (2022), Popkova et al. (2021), in which they note the desire of highly qualified and, in particular, digital personnel to reveal their human potential, the following hypothesis is put forward in this article.

H_2: the movement of labor resources towards the "core" of the digital economy is determined by the conditions that contribute to the disclosure of their human potential.

The economic meaning of the hypothesis put forward is that in the conditions of the Fourth Industrial Revolution, ensuring gender equality among digital personnel (implementation of SDG5), guaranteeing social justice in the segment of highly qualified personnel in the labor market (implementation of SDG10), ensuring decent employment for digital personnel, creating knowledge-intensive jobs to unlock human potential in industry 4.0 (implementation of SDG8 and SDG9) contribute to improving the efficiency of the migration institute (implementation of SDG16), strengthen and develop international partnership in the field of migration (implementation of SDG17), creating and stimulating the movement of labor resources towards the global "core" of the digital economy.

In order to fill the identified gap in the literature, search for answers to the posed RQs, as well as test the hypotheses put forward, this article conducts econometric modeling of the dependence of quality manifestations in industry 4.0, which are directly related

to the human resources, on the movement of labor resources towards the "core" of the digital economy.

3. EXPERIMENTAL DESIGN AND METHODOLOGY

The factual basis of this study is statistical materials on the topic of global competitiveness from an authoritative source: IMD (2023). The sample includes all 72 countries that are covered by statistics (for which there are no data gaps) by IMD (2023), that is, representing the global "core" of the digital economy. For the most complete coverage of the digital age, the time frame of the study is a five-year period from 2017 to 2022.

Statistics for the last five years are combined into a single array of data. This made it possible to form a statistical database of the study, including 360 observations, which contributed to obtaining accurate and reliable results. The sample is given in the data table attached to this article (appendix 1). The article assumes the following experimental design and methodology, taking into account the set of tasks.

The first task is to determine the impact of the movement of labor resources towards the "core" of the digital economy on quality in industry 4.0. This task is solved using the regression analysis method. To find the answer to RQ_1, the factor variable is the indicator "foreign highly-skilled personnel" (it will be denoted as FHSP) in the formed sample, which quantitatively characterizes the movement of labor resources towards the global "core" of the digital economy. The dependent variables are the following:

- The indicator "digital/technological skills" (it will be denoted as DTS), which quantitatively characterizes the level of development of digital (technological) competencies of human resources used in industrial and manufacturing engineering;
- The indicator "use of big data and analytics" (it will be denoted as BDA), which quantitatively characterizes the activity of using Big data and their "smart" analytics based on artificial intelligence (AI) for intelligent decision support for quality management in industry 4.0;
- The indicator "digital transformation in companies" (it will be denoted as DTC), which quantitatively characterizes the strength of global brands of products in industry 4.0;

To find the answer to RQ_2, the indicator "equal opportunity" (it will be denoted as EQOP) acts as a factor variable, quantitatively characterizing the conditions for the disclosure of their human potential in industry 4.0: gender equality among digital personnel, social justice in the segment of highly qualified personnel of the labor market, decent employment opportunities for digital personnel, as well as the availability of knowledge-intensive jobs in industry 4.0. The dependent variable is the indicator "foreign highly-skilled personnel" (FHSP). With the notation introduced, we obtain the following research model:

$$\begin{cases} DTS=\alpha_{DTS}+\beta_{DTS}*FHSP, \\ BDA=\alpha_{BDA}+\beta_{BDA}*FHSP, \\ DTC=\alpha_{DTC}+\beta_{DTC}*FHSP, \\ IAB=\alpha_{IAB}+\beta_{IAB}*FHSP, \\ FHSP=\alpha_{FHSP}+\beta_{FHSP}*EQOP. \end{cases} \quad (1)$$

All indicators in model (1) are measured in points from 1 (worst) to 10 (best), which ensures complete comparability of data, consistency of model (1) and simplicity of qualitative interpretation of its economic meaning. The reliability of the equations of paired linear regression is determined using a series of tests: correlation analysis, the standard error of Fisher's F-test and Student's t-test, which allow to define the error of the regression equations and their reliability at the significance level to which they correspond. Hypothesis H_1 is considered proven in the case of positive values of the regression coefficients β_{DTS}, β_{BDA}, β_{IAB} and β_{DTC} in the model (1). Hypothesis H_2 is considered proven in the case of a positive value of the regression coefficient β_{FHSP} in the model (1).

The second task is to identify the prospects for improving quality in industry 4.0 through optimizing the movement of labor resources towards the "core" of the digital economy. To solve this problem, two forecasts for the "Decade of Action" (until 2030) are made using the simplex method based on the system of equations (1).

The first forecast assumes overcoming inequality in the labor market of the global "core" of the digital economy. To do this, the maximum (10 points) value of the indicator "equal opportunity" (EQOP) is substituted into the model (1) and the predicted values of the other indicators depending on it (FHSP and, as a consequence, DTS, BDA, IAB and DTC) are determined.

The second forecast suggests the full disclosure of the potential for attracting foreign personnel. To achieve this, the maximum (10 points) value of the indicator "foreign highly-skilled personnel" (FHSP) is substituted into the model (1) and the predicted values of the other indicators depending on it (DTS, BDA, IAB and DTC) are determined. The trend analysis method is used to identify the increase in the values of all variables for each scenario.

The third task is to create a promising mechanism for quality management in industry 4.0 through the movement of labor resources towards the "core" of the

digital economy. Based on the results of econometric modeling, the article provides a qualitative interpretation of this mechanism, revealing cause-and-effect relationships, and presents its graphic illustration. The authors' mechanism reflects the sequence of stages and thus explains the patterns of improving the quality of industry 4.0 products through the movement of labor resources towards the "core" of the digital economy, and also offers framework recommendations for improving quality management through the regulation of migration flow and HRM in industry 4.0.

4. RESULTS

4.1. The impact of the movement of labor resources towards the "core" of the digital economy on quality in Industry 4.0

To solve the first task of this study and determine the impact of the movement of labor resources towards the "core" of the digital economy on quality in industry 4.0, a regression analysis of the previously formed statistical database of this study (Appendix 1) is carried out. As a result, the parameters of the research model (1) are refined and a system of equations (2) is obtained:

$$\begin{cases} DTS=5.2190+0.3163*FHSP, \\ BDA=3.5382+0.2870*FHSP, \\ DTC=4.3936+0.2731*FHSP, \\ IAB=1.8450+0.8179*FHSP, \\ FHSP=-0.2275+0.9232*EQOP. \end{cases} \quad (2)$$

The system of equations (2) shows that an increase in the indicator "foreign highly-skilled personnel" (FHSP) by 1 point is accompanied by an increase in the following indicators: "digital/technological skills" (DTS) – by 0.3163 points, "use of big data and analytics" (BDA) – by 0.2870 points, "image abroad or branding" (IAB) – by 0.2731 points and "digital transformation in companies" (DTC) – by 0.8179 points. Since the regression coefficients β_{DTS}, β_{BDA}, β_{IAB} and β_{DTC} in model (2) are positive, this proves hypothesis H_1. An increase in the indicator "foreign highly-skilled personnel" (FHSP) by 0.9232 points is achieved by increasing the indicator "equal opportunity" (EQOP) by 1 point. Since the regression coefficient β_{FHSP} in model (2) is positive, this proves hypothesis H_2. The reliability of regression equations from model (2) is evaluated using detailed regression statistics and the results of variance analysis from Tables 1-5.

Table 1. Regression analysis of the dependence of digital/technological skills on foreign highly-skilled personnel in 2017-2022.

Regression statistics	
Multiple R	0.4961
R-Square	0.2461
Adjusted R-Square	0.2440
Standard Error	0.9473
Observations	360

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	104.8971	104.8971	116.8952	$9.1*10^{-24}$
Residual	358	321.2550	0.8974		
Total	359	426.1521			

	Coeffi-cients	*Standard Error*	*t-Stat*	*P-Value*	*Lower 95%*	*Upper 95%*
Constant	5.2190	0.1647	31.6943	$6*10^{-106}$	4.8952	5.5428
FHSP	0.3163	0.0293	10.8118	$9.1*10^{-24}$	0.2587	0.3738

Source: calculated and compiled by the authors.

The results from Table 1 show that the change in the level of digital/technological skills in the global "core" of the digital economy in 2017-2022 by 49.61% is determined by the influx of foreign highly-skilled personnel. The standard error is relatively small (0.9473). The significance of F is 9.1*10-24, therefore, the significance level is the highest: 0.001. Critical F=11.0085 with 1 factor variable (k1=m=1) and 360 observations (k2=n-m-1=360-1-1) at a given significance level.

The observed F exceeds the critical value and is 116.8952. Therefore, Fischer's F-test has been passed. At a given significance level at 359 degrees of freedom, the critical t=2.5896. The observed t (with a factor variable) exceeds the critical value and is 10.8118. Therefore, Student's t-test has been passed. The tests carried out mean that the error is very small – less than 0.1%.

Table 2. Regression analysis of the dependence of use of big data and analytics on foreign highly-skilled personnel in 2017-2022.

Regression statistics	
Multiple R	0.5621
R-Square	0.3159
Adjusted R-Square	0.3140
Standard Error	0.7227
Observations	360

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	86.3493	86.3493	165.3259	$2.3*10^{-31}$
Residual	358	186.9825	0.5223		
Total	359	273.3317			

	Coeffi-cients	*Standard Error*	*t-Stat*	*P-Value*	*Lower 95%*	*Upper 95%*
Constant	3.5382	0.1256	28.1648	$7.9*10^{-93}$	3.2912	3.7853
FHSP	0.2870	0.0223	12.8579	$2.3*10^{-31}$	0.2431	0.3308

Source: calculated and compiled by the authors.

The results from Table 2 show that the 56.21% change in the activity of use of big data and analytics in the global "core" of the digital economy in 2017-2022 is determined by the influx of foreign highly-skilled personnel. The standard error is relatively small (0.7227). The significance of F is 2.3*10-31, therefore, the significance level is the highest: 0.001. Critical F=11.0085 with 1 factor variable (k1=m=1) and 360 observations (k2=n-m-1=360-1-1) at a given significance level.

The observed F exceeds the critical value and is 165.3259. Therefore, Fischer's F-test has been passed. At a given significance level at 359 degrees of freedom, the critical t=2.5896. The observed t (with a factor variable) exceeds the critical value and is 12.8579. Therefore, Student's t-test has been passed. These tests mean that the error is very small – less than 0.1%.

Table 3. Regression analysis of the dependence of digital transformation in companies on foreign highly-skilled personnel in 2017-2022.

Regression statistics	
Multiple R	0.7970
R-Square	0.6352
Adjusted R-Square	0.6342
Standard Error	1.0608
Observations	360

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	701.4257	701.4257	623.3662	$2.1*10^{-80}$
Residual	358	402.8297	1.1252		
Total	359	1104.2554			

	Coeffi-cients	*Standard Error*	*t-Stat*	*P-Value*	*Lower 95%*	*Upper 95%*
Constant	1.8450	0.1844	10.0057	$6*10^{-21}$	1.4823	2.2076
FHSP	0.8179	0.0328	24.9673	$2.1*10^{-80}$	0.7534	0.8823

Source: calculated and compiled by the authors.

The results from Table show that the change in the level of digital transformation in companies in the global "core" of the digital economy in 2017-2022 by 52.33% is determined by the influx of foreign highly-skilled personnel. The standard error is relatively small (0.7610). The significance of F is 1.1*10-26. Therefore, the significance level is the highest: 0.001. Critical F=11.0085 with 1 factor variable (k1=m=1) and 360 observations (k2=n-m-1=360-1-1) at a given significance level.

The observed F exceeds the critical value and is 135.0250. Therefore, Fischer's F-test has been passed. Critical t=2.5896 at a given significance level at 359 degrees of freedom. The observed t (with a factor variable) exceeds the critical value and is 11.6200. Therefore, Student's t-test has been passed. The tests carried out mean that the error is very small – less than 0.1%.

Table 4. Regression analysis of the dependence of image abroad or branding on foreign highly-skilled personnel in 2017-2022.

Regression statistics	
Multiple R	0.7346
R-Square	0.5396
Adjusted R-Square	0,5384
Standard Error	1.1612
Observations	360

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	565.9052	565.9052	419.6673	$2.8*10^{-62}$
Residual	358	482.7492	1.3485		
Total	359	1048.6543			

	Coeffi-cients	*Standard Error*	*t-Stat*	*P-Value*	*Lower 95%*	*Upper 95%*
Constant	-0.2275	0.2797	-0.8132	0.4166	-0.7776	0.3226
EQOP	0.9232	0.0451	20.4858	$2.8*10^{-62}$	0.8346	1.0119

Source: calculated and compiled by the authors.

The results from Table show that the change in the strength of image abroad or branding in the global "core" of the digital economy in 2017-2022 by 79.70% is determined by the influx of foreign highly-skilled personnel. The standard error is relatively small (1.0608). The significance of F is 2.1*10-80. Therefore, the significance level is the highest: 0.001. Critical F=11.0085 with 1 factor variable (k1=m=1) and 360 observations (k2=n-m-1=360-1-1) at a given significance level.

The observed F exceeds the critical value and amounts to 623.3662. Therefore, Fischer's F-test has been passed. Critical t=2.5896 at a given level of significance at 359 degrees of freedom. The observed t (with a factor variable) exceeds the critical value and amounts to 24.9673. Therefore, Student's t-test has been passed. The tests carried out mean that the error is very small – less than 0.1%.

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Table 5. Regression analysis of the dependence of foreign highly-skilled personnel on equal opportunity in 2017-2022.

Regression statistics	
Multiple R	0.5233
R-Square	0.2739
Adjusted R-Square	0.2718
Standard Error	0.7610
Observations	360

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	78.2036	78.2036	135.0250	$1.1*10^{-26}$
Residual	358	207.3462	0.5792		
Total	359	285.5498			

	Coeffi-cients	*Standard Error*	*t-Stat*	*P-Value*	*Lower 95%*	*Upper 95%*
Y-intercept	4.3936	0.1323	33.2114	$2*10^{-111}$	4.1334	4.6537
Foreign highly-skilled personnel	0.2731	0.0235	11.6200	$1.1*10^{-26}$	0.2269	0.3193

Source: calculated and compiled by the authors.

The results from Table indicate that the influx of foreign highly-skilled personnel in the global "core" of the digital economy in 2017-2022 by 73.46% is determined by equal opportunity. The standard error is relatively small (1.1612). The significance of F is 2.8*10-62. Therefore, the significance level is the highest: 0.001. The critical F=11.0085 with 1 factor variable (k1=m=1) and 360 observations (k2=n-m-1=360-1-1) at a given significance level.

The observed F exceeds the critical value and is 419.6673. Therefore, Fischer's F-test has been passed. The critical t=2.5896 at a given significance level at 359 degrees of freedom. The observed t (with a factor variable) exceeds the critical value and is 20.4858. Therefore, Student's t-test has been passed. The tests carried out mean that the error is very small – less than 0.1%.

Thus, the obtained results allow us to draw the first conclusion that the movement of labor resources towards the "core" of the digital economy contributes to improving the quality of products in industry 4.0 through: 1) development of digital (technological) competencies of human resources used in industrial and manufacturing engineering (correlation: %); 2) increasing the activity of using Big data and its "smart" analytics based on artificial intelligence (AI) for intelligent decision support for quality management in industry 4.0 (correlation: %); 3) increasing the level and pace of digital transformation and digital competitiveness of industrial enterprises in industry 4.0 (correlation: %); 4) strengthening the power of global brands of product in industry 4.0 (correlation: %).

And the second conclusion is that the movement of labor resources towards the "core" of the digital economy is determined by the conditions for the disclosure of their human potential (correlation: %): gender equality among digital personnel, social justice in the segment of highly qualified personnel of the labor market, decent employment opportunities for digital personnel, as well as the availability of knowledge-intensive jobs in industry 4.0.

4.2 The prospect of improving quality in industry 4.0 through optimizing the movement of labor resources towards the "core" of the digital economy

To solve the second task of this study and identify the prospects for improving quality in industry 4.0 through optimizing the movement of labor resources towards the "core" of the digital economy, two forecasts for the "Decade of action" (up to 2030) have been compiled using the simplex method based on the system of equations (2).

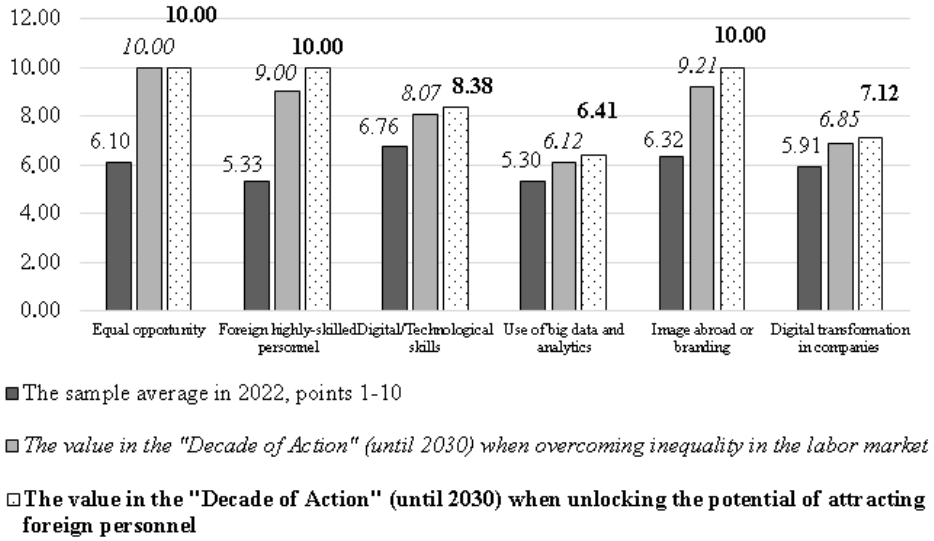

Figure 1. The prospect of improving quality in industry 4.0 through optimizing the movement of labor resources towards the "core" of the digital economy in the "Decade of Action"
Source: calculated and constructed by the authors.

The first forecast in Fig. 1 demonstrates the advantages of overcoming inequality (increasing equal opportunity by 64.07%) in the labor market of the global "core" of the digital economy, related to:

- The increase in the influx of foreign highly-skilled personnel by 68.90% (from 5.33 points in 2022 to 9.00 points by 2030);
- The increase in the level of digital/technological skills by 19.29% (from 6.76 points in 2022 to 8.07 points by 2030);
- The growth in the activity of use of big data and analytics by 15.43% (from 5.30 points in 2022 to 6.12 points by 2030);
- The increase in the level of digital transformation in companies by 45.66% (from 6.32 points in 2022 to 9.21 points by 2030);
- Strengthening the power of image abroad or branding by 15.87% (from 5.91 points in 2022 to 6.85 points by 2030).

The second forecast reflects the advantages of full disclosure of the potential of attracting foreign personnel (increasing the inflow of foreign highly-skilled personnel by 87.67%) to the global "core" of the digital economy, including:

- The increase in the level of digital/technological skills by 23.87% (from 6.76 points in 2022 to 8.38 points by 2030);

- The growth of use of big data and analytics by 20.90% (from 5.30 points in 2022 to 6.41 points by 2030);
- The increase in the level of digital transformation in companies by 58.47% (from 6.32 points in 2022 to 10.00 points by 2030);
- Strengthening the power of image abroad or branding by 20.44% (from 5.91 points in 2022 to 7.12 points by 2030).

Thus, the obtained results indicate a significant prospect of improving quality in industry 4.0 in the "Decade of Action" through optimizing the movement of labor resources towards the "core" of the digital economy. Overcoming inequality in the labor market will allow almost completely (by 90%) to unlock the potential of the influx of highly skilled labor migrants into the global "core" of the digital economy (to reach 9 points out of 10) – the remaining 10% of this potential is explained by the influence of other factors beyond the model (2), in particular, the factor of quality of life.

4.3 The mechanism of quality management in industry 4.0 through the movement of labor resources towards the "core" of the digital economy

To solve the third problem and create a promising quality management mechanism in industry 4.0 through the movement of labor resources towards the "core" of the digital economy, a qualitative interpretation of the results of econometric modeling (in model (2)) is given, and the mechanism that reveals the cause-and-effect relationships of this management process is presented in graphical form (Fig. 2).

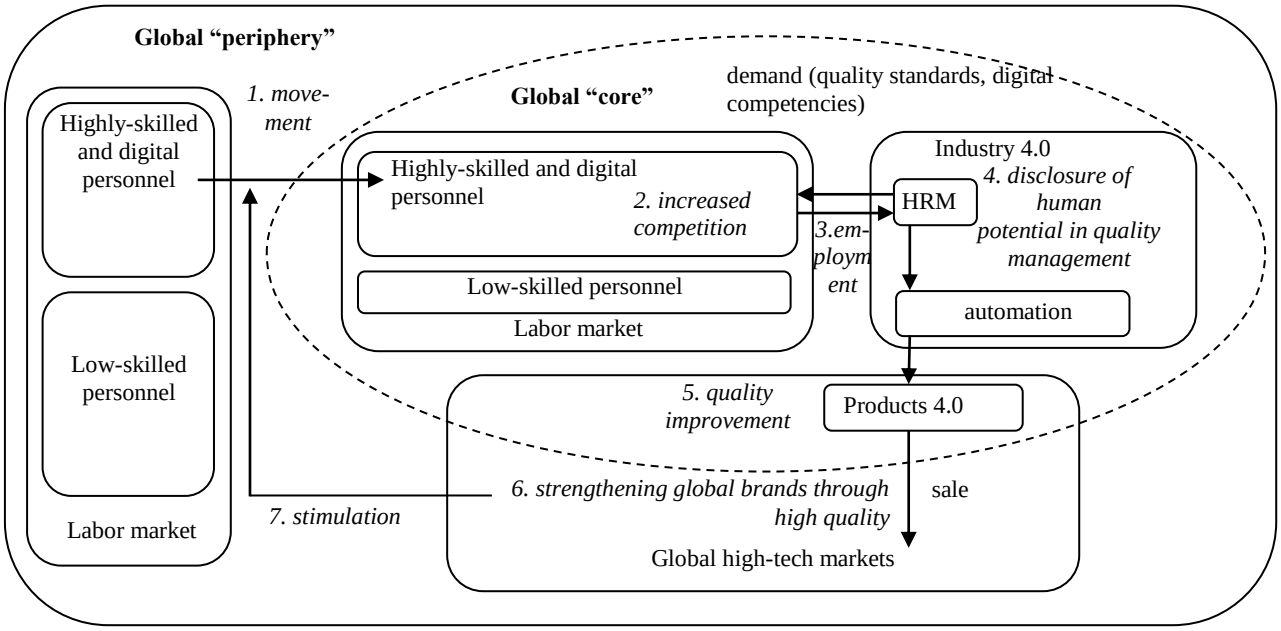

Figure 2. The mechanism of quality management in industry 4.0 through the movement of labor resources towards the "core" of the digital economy
Source: developed by the authors.

The authors' mechanism in Figure 2 reflects the sequence of stages and thus explains the pattern of improving the quality of products in industry 4.0 through the movement of labor resources towards the "core" of the digital economy. At the first stage, there is a movement of skilled and digital personnel from the labor market of the global "periphery" to the labor market of the global "core" of the digital economy. At the second stage, this ensures an increase in the level of competition among highly-skilled personnel in the labor market of the global "core" of the digital economy.
At the third stage, the most competitive highly-skilled and digital personnel are employed in knowledge-intensive jobs in industry 4.0. At the fourth stage, their human potential is revealed through quality management in industry 4.0. At the fifth stage, an increase in the quality of products of industry 4.0 is achieved, and they are sold in global high-tech markets. At the sixth stage, global brands of products of industry 4.0 are strengthened due to their high quality. At the seventh stage, this creates natural market incentives for further movement and an increase in the flow of highly-skilled and digital personnel towards the global "core" of the digital economy.

The developed mechanism also offers framework recommendations for improving quality management through the regulation of migration flow and HRM in industry 4.0 – ensuring social justice in the labor market. In particular, it is recommended to reduce the entry barriers of segment of highly-skilled and digital personnel of the labor market of the global "core" of the

digital economy. Employers are also recommended to apply a fair system for selecting the best personnel in industry 4.0, establishing a demand for highly qualified personnel who know quality standards and have digital competencies.

5. DISCUSSION

The article contributes to the literature through the development of scientific provisions of the concept of labor migration, rethinking the essence of the movement of labor resources from the global "periphery" towards the global "core" in the context of the Fourth Industrial Revolution, as well as clarifying the implications of this process for quality in industry 4.0. The theoretical significance of the article is that it has identified the features of the movement of labor resources towards the global "core" in the digital economy from the standpoint of quality in industry 4.0 (Table 6).

Table 6. Features of the movement of labor resources towards the global "core" in the digital economy from the standpoint of quality in industry 4.0

The aspect of comparison	The essence of the process of labor resources movement towards the global "core"	
	in the pre- digital era	in the digital economy
The composition of the labor force moving towards the global "core" and their ability to meet the need of the economy for human resources to improve quality	low-skilled labor force that does not meet the needs of the economy for human resources to improve quality (Chan, 2014; King, 2022; Popkova, 2021)	highly qualified workforce – digital personnel – meeting the need of the digital economy for human resources to improve quality in industry 4.0
The power of foreign personnel in the labor market of the global "core" from the standpoint of quality	low due to lack of knowledge of quality standards and competence deficiencies to comply with them (Jacobs, 2019; Finnsdottir, 2019; Chan, 2019)	high thanks to knowledge of quality standards of industry 4.0 and possession of digital competencies to comply with them
Conditions that attract labor resources to the global "core" and their readiness to contribute to quality improvement	higher quality of life (than in the global "periphery"), low readiness to contribute to quality improvement (Bisho and Sam, 2022; Popkova, 2023; Amit and Chachashvili-Bolotin, 2018)	wider opportunities for the disclosure of the human potential of digital personnel (than in the global "periphery"), high readiness to contribute to quality improvement in industry 4.0
Implications of the influx of foreign labor resources for the economy of the global "core"	overcoming the shortage in the labor market in the segment of low-skilled personnel, fuller utilization of production capacities, quantitative growth of production (Jakobson and Kalev, 2020; Yu et al., 2022; Liu, 2022)	increased competition in the labor market in the segment of highly-skilled and, in particular, digital personnel, quality improvement in industry 4.0

Source: developed by the authors.

As shown in Table 6, unlike Chan (2014), King, (2022), Popkova (2021), the workforce moving towards the global "core" in the digital economy is dominated not by low-skilled (as it was in the pre-digital era), but by highly-skilled workforce - digital personnel, – meeting the need for human resources of the digital economy to improve quality in industry 4.0.

Unlike Jacobs (2019), Finnsdottir (2019), Chan (2019), the power of foreign personnel in the labor market of the global "core" in terms of quality in the digital economy is not low (as it was in the pre-digital era), but high due to knowledge of quality standards of industry 4.0 and possession of digital competencies to comply with them.

In contrast to Bisho and Sam (2022), Popkova (2023), Amit and Chachashvili-Bolotin 2018), the conditions attracting labor resources to the global "core" in the digital economy are not so much related to a higher quality of life than in the global "periphery" (which was crucial for the pre-digital era), and with wider opportunities for the disclosure of the human potential of digital personnel (than in the global "periphery"), which implies their high readiness to contribute to quality improvement in industry 4.0.

Unlike Jakobson and Kalev (2020), Yu et al. (2022), Liu (2022), the consequences of the influx of foreign labor resources for the global "core" in terms of working conditions are expressed not only quantitatively (overcoming the shortage in the labor market in the segment of low-skilled personnel, fuller utilization of production capacities, quantitative growth of production - as it was in the pre-digital era), but also qualitatively - in the growth of competition in the labor market in the segment of highly qualified and, in particular, digital personnel, quality improvement in industry 4.0.

6. CONCLUSION

As a result of the conducted research, it can be concluded that the purpose set in it has been achieved thanks to the successful solution of all three tasks. The main result of the research was the development of a scientific and practical approach to quality management in industry 4.0 through the movement of labor resources towards the "core" of the digital economy. The essence of the new approach lies in the fact that, firstly, it takes into account the previously unknown features of the movement of labor resources towards the global "core" in the digital economy from the standpoint of quality in industry 4.0 identified in the article.

The first feature is that the structure of labor resources moving towards the global "core" is dominated by highly-skilled labor resources – digital personnel – meeting the need of the digital economy for human resources to improve quality in industry 4.0. The second feature is the high power of foreign personnel in the labor market of the global "core" from the standpoint of quality due to knowledge of quality standards of industry 4.0 and possession of digital competencies to comply with them.

The third feature is that the conditions that attract labor resources to the global "core" are associated with broader opportunities for the disclosure of the human potential of digital personnel (than in the global "periphery"), which implies a high readiness of migrant workers to contribute to quality improvement in industry 4.0. The fourth feature is that the implications of the influx of foreign labor resources for the economy of the global "core" are the growth of competition in the labor market in the segment of highly-skilled and, in particular, digital personnel, quality improvement in industry 4.0.

Secondly, the authors' approach is based on a specially developed quality management mechanism in industry 4.0 through the movement of labor resources towards the "core" of the digital economy. The framework recommendations for improving quality management through the regulation of migration flow and HRM in industry 4.0, which activate the proposed mechanism, are: 1) reducing the entry barriers of the segment of highly qualified and digital personnel of the labor market of the global "core" of the digital economy; 2) fair selection of the best personnel by employers in industry 4.0 through the demand for highly qualified personnel who know quality standards and possess digital competencies

The theoretical significance of the article lies in the fact that it has supplemented the concept of labor migration due to a more complete consideration of the specifics of the digital context. The article has clarified the implications of the movement of labor resources to the "core" of the digital economy for the quality of products in industry 4.0. The main conclusion of this study is that the movement of labor resources towards the "core" of the digital economy opens up additional opportunities to improve the product quality of industry 4.0, which the authors' recommendations on ensuring social justice in the labor market will help to implement.

The practical significance of the authors' conclusions and recommendations is that the developed scientific and practical approach to quality management in industry 4.0 through the movement of labor resources towards the "core" of the digital economy will increase the competitiveness of products of industry 4.0 in the global high-tech markets and thereby accelerate the successful completion of the Fourth Industrial Revolution and bring the transition to the Fifth Industrial Revolution closer.

Migration policy implication is related to the fact that the authors' recommendations will ensure an increase in the effectiveness of this policy by optimizing the flow of labor resources towards the global "core", which will allow: 1) reduce the costs of migration policy by switching from measures of social support for migrant workers to market self-regulation (upon condition of social justice); 2) to increase the advantages in the form of increasing the share of highly-skilled foreign personnel (among migrant workers), simplify the process of their employment and maximize their contribution to improving the quality of products of industry 4.0.

The social significance of the article is expressed in the fact that the new scientific and practical approach to quality management in industry 4.0 will ensure the freedom of movement of labor resources towards the "core" of the digital economy; expand the opportunities both for the employment of migrant workers in knowledge-intensive jobs and for the disclosure of their human potential. In general, this will bring the segment of highly qualified personnel of the labor market of the global "core" of the digital economy in line with SDG5, SDG10, SDG8, SDG9, SDG16 and SDG17

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