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Analyzing The Systemic Impact of Information Technology Development Dynamics on Labor Market Transformation

Dmitry Rodionov[1], Anastasia Gracheva[1], Evgenii Konnikov[1], Olga Konnikova[2], Darya Kryzhko[1*]

[1]*Graduate School of Economics and Technologies, Peter the Great St. Petersburg Polytechnic University, Saint Petersburg, 195251, Russia*
[2]*Department of Marketing, Saint-Petersburg State University of Economics, Saint Petersburg, 191023, Russia*

Abstract. Today, humanity is on the verge of the fourth industrial revolution. This can result in a radical transformation of all aspects of society. Information technology is the core of the fourth industrial revolution. The application variety of modern information technologies determines the infinite vectors of their use, which ultimately become the overwhelming number of instruments for life simplifing. Professional activity sphere is also being transformed under the influence of information technology development. However, this transformation process is extremely ambiguous. In connection with this specificity, the purpose of this study is a systematic analysis of the influence of the information technology development dynamics on the transformation of the labor market. The hypothesis assumes that there is a relationship between technology development and changes in the labour market. This research examine digitalization impact on unemployment level and the process of gradual extinction of certain professions. As the results authors defined mathematical formalization of the alleged links and formulate the main vectors of labour market transformation under the digital technologies development.

Keywords: ICT index; Information technology; Innovation index; Labor market; Unemployment rate

1. Introduction

The labor market is one of the most significant economic institutions. Like any other sphere, the labor market is constantly going through changes, and the rapid development of information technology has a direct relation to it (Berawi, 2021). Routine, monotonous work can be automated. There are many professions that are gradually transforming under the influence of digital technologies spreading. Also, experts predict that developed countries are going to lose up to 5 million jobs in the next five years alone due to digital technology and robotization, and this number will only increase further on (Zaytsev et al., 2021). RANEPA experts claim that 98% of drivers, 94% of accountants and economists, 72% of movers will be eventually replaced by robots (Semenets, 2019). The purpose of this paper is to analyze systematically the impact of the dynamics of information technology development on the transformation of the labor market. The hypothesis assumes that there

*Corresponding author's email: darya.kryz@yandex.ru, Tel.: +7 (812) 534-73-31; Fax: +7 (812) 534-73-31
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is a systemic dependence between the development of digital technology, its implementation in various areas and changes in the labor market: unemployment rate, emergence of new professions, the gradual extinction of certain other professions.

Within the existing theoretical framework, it is possible to single out studies describing the impact of information and communication technologies (hereinafter called ICT) on employment at the moment in the world in general. Thus, in the work of Van-Roy et al. (2018), the authors analyzed the changes in 20 thousand companies in 22 European countries from 2003 to 2012 and as result showed that the positive impact of innovation can only be observed in the high and medium technology production sector, while being insignificant in low technology production and in the service sector. Dengler and Matthes (2018) came to similar conclusion the study of routine occupations, which could be replaced by computers or computer-controlled machines, in Germany. Only certain tasks could be performed by machine labor, not the whole process. The impact of digital transformation varies from occupation, the authors believe. There are many occupation what cannot be performed by a computer. The potential to be replaced by a machine is high in professions that do not require special skills, while this potential is lower in complex professions. Also, Digilina and Teslenko (2019) concluded that it is inevitable that the labor market is impacted by the ICT. New digital technologies replace human workers in production, change the nature of their work and leisure time, distribute working time in a different way. The authors conclude that the labor market will be affected by digital technologies, mostly in the high-tech manufacturing sector. However, Garcia-Murillo et al. (2018) come to slightly different results. Technological changes, in their opinion, will not necessarily contribute to the transformation of the labor market, because the impact of technology development, in the long run, is still unknown. The study also arrives at other interesting conclusions: ICTs have helped move production from high-wage countries to low-wage countries, and the development of digital networks facilitates labor migration, putting pressure on wage in middle- and high-income countries, and developing wage inequalities. The authors also looked at changes in education: new occupations require higher levels of education, resulting in higher wages. Professions related to science, engineering, mathematics, and technical fields are expected to see an increase in specialists. Atalay et al. (2018) agree with the conclusions about income inequality that changes in the labor market have caused. In a 2018 paper, they analyzed 4.2 million newspaper job ads job to understand how ICT developments have affected hiring requirements for recruitment applicants. It was information from newspapers such as the Boston Globe, New York Times, and Wall Street Journal from 1960 to 2000. The authors came to the following conclusions: the introduction of new technologies increased the share of non-routine analytical tasks, which caused income inequality. It has to be noted, however, that ICT development directions are extremely differentiated and essentially aggregate the totality of technological solutions, perceived by consumers as an information resource designed to minimize labor intensity and open new areas of consumption. The article by Dekle (2020) analyzes Japan, which is an antipode of Russia in terms of automation and technology implementation. In Japan they are not worried about the fact that robots will cause mass unemployment, as they believe that robots, on the contrary, help due to the chronic shortage of workers. The authors noted positive effect of robots on Japanese employment and on aggregate demand by the data of last 35 years. Thus, we can formulate the following key conclusion - only monotonous work can be replaced by machine labor. The more automation increases the wider becomes inequality in wage rates. Moreover creating new innovation products in technology sphere have contributed the production shift from high-wage to low-wage countries.

Separately, we should consider the studies arguing that the introduction and proliferation of automated processes will only result in problems, mainly unemployment. Thus, in an article by Garcia-Murillo (2018), the authors concluded that the current state of transformation and automation will accelerate in the future. This process is hard to influence, so the solution is not to resist these changes, but to mitigate the negative consequences that they may entail. In the article by Digilina and Teslenko (2019), the authors also concluded that the nature of the labor market will gradually change, which makes it important at the administrative level to realize this new reality in time and to neutralize the negative impact by making appropriate managerial decisions. The article by Zemtsov et al. (2019) analyzed the Russian labor market and concluded which regions of the country will be more affected by the transition to the digital economy.

In conclusion, we should consider sociological studies that analyze people's attitudes towards working with robots. The study by Savela et al. (2021) aimed to research the consequences of introducing robots into the work environment. The participants of the study were asked to present a hypothetical situation in which they had to work in a team. The number of robots varied across number of humans included in control group. The result of the study suggests that when humans are a minority, they feel less comfortable, which has adverse consequences in communication and productivity.

According to the results of the study of the existing theoretical basis, it can be argued that the topic of the impact of ICT development on the labor market has been studied primarily from one angle, while the issue of the impact of certain aspects of ICT development on the population's perception of available professional development perspectives, as well as the impact of negative changes in the labor market on the information environment, haven't been studied as thoroughly. Moreover, the considered issues were studied in isolation and do not allow forming a holistic understanding, which is the purpose of this study.

2. Methodology

Based on the results of the theoretical study, a list of systematically related variables can be compiled. It is assumed that technology development should influence changes in the labor market. First of all, the ICT development index should be used as a kind of centroid that can influence on other parameters or depend on them. ICT development is considered via indicators such as innovation index, an index of government readiness to implement ICT, government spending on research and development, robotization rate, and ICT implementation feasibility. Also, in addition to ICT development indicators, the information environment and its negative tone should be considered. It is assumed that we can measure the changing of labor market index under the influence of ICT index. Figure 1 presents the conceptual model of this study.

The most effective tool for testing this model is regression analysis. For the purposes of the analysis, a sample of 15 countries leading in the ICT index was formed: Japan, Germany, USA, South Korea, Iceland, Switzerland, Denmark, UK, Netherlands, Hong Kong, New Zealand, Australia, Singapore, Sweden and Russia. Most of these countries are present in the top 20 on the ICT index, and while Russia holds a lower position, it is included due to its significance for the applied interpretation of the results of the study. However, it had been decided not include more countries with lower ICT index in the sample. The reason is that there are relatively small share of countries with hight ICT index. Thus, adding additional data could affect on research results because there is huge difference between the number of low and hight ICT index countries.

Therefore, in this paper it was decided to focus on the leading countries in terms of technology development. Let us examine the components of the conceptual model in more detail. Data on the robotization rate, calculated per 10,000 workers, are aggregated within the International Federation of Robotics resource.

The source of data on the ICT index is the International Telecommunication Union. This index characterizes the level of ICT penetration and its uses in a country. This index consists of several components: ICT accessibility, which accounts for 40% of the index, ICT usage, 40%, and ICT skills, 20%. Accessibility includes such factors as: fixed phone subscriptions per 100 inhabitants, mobile phone subscriptions per 100 inhabitants, bandwidth (bits per second) per user, the share of households with computers, the share of households with internet access. ICT use consists of a proportion of people using the Internet, fixed high-speed Internet subscriptions per 100 inhabitants, active mobile Internet subscriptions at 256 kbit/second or higher per 100 inhabitants. ICT skills include literacy rate, secondary and tertiary education enrollment rates.

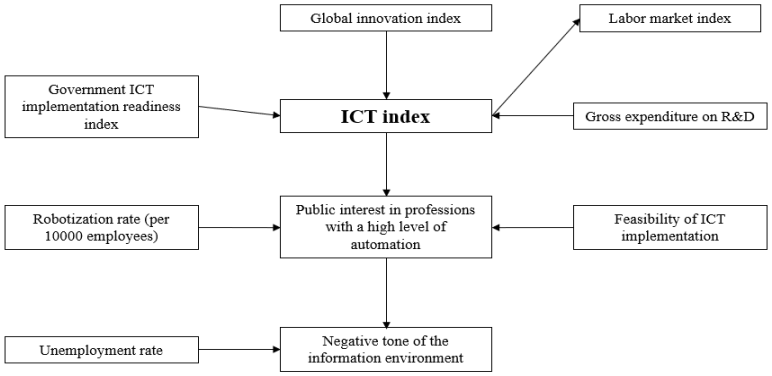

Figure 1 Conceptual model of the study

The robotization rate is considered in terms of positive or negative population response (actual and potential representatives of the labor market). While the ICT index characterizes the level of ICT penetration and application of ICT among the country's population, which, in turn, determines the level of the population's immersion in the current technological environment, and the ICT implementation readiness index reflects the availability of ICT primarily for employers, the robotization rate reflects another unique aspect – the potential awareness of the need to interact with automated solutions in the scope of professional activity and the awareness of the decreasing value of low-skilled labor, or labor that doesn't require competent interaction with ICT. In connection with the above, we consider the use of this parameter as a separate indicator appropriate, which is also confirmed by regression analysis.

Oxford Insights is calculated the government AI readiness only since 2017. The index is calculated based on the digitalization index, the presence of startups associated with artificial intelligence, the government efficiency index.

The global innovation index is calculated annually since 2011. The index includes many factors, including the political environment in the country, the availability of a favorable environment for business, various indicators of education, access to ICT, the degree of market development, business and government contribution to research. Gross expenditure on research and development includes the number of researchers, R&D expenditure as a share of GDP and the quality of research institutions. This index serves as an indicator of a country's commitment to technology development. ICT penetration capacity show the opportunities for information technologies applying in all production spheres over the country.

The interest of the population in professions with a high level of automation can be expressed by the dynamics of Google search for vacancies in these professions. Five professions were selected based on the automation index for 2018 developed by the University of Hawaii (Hawai'i Career Explorer, 2020). These occupations are electrician, farmer, dishwasher, gardener, and logger. The research was done using Google Trends. The information for these five occupations from 2005 to 2019 was collected using official language of each country concidered. The trend in popularity for each profession was calculated as the level of interest in the topic in relation to the highest score in the table for a particular region and time period. 100 points means the highest level of popularity of a query, 50 - a query that is half as popular as the first case, 0 points mean insufficient data about the query in question. After collection, year average was taken, and data were generated for fifteen countries for five occupations from 2005 to 2019, then average for all occupations was taken, i.e., generated an interest index expressed through Google searches for vacancies of occupations with high level of automation for selected countries from 2005 to 2019.

The unemployment rate is the ratio of unemployed to the labor force (the sum of employed and unemployed), defined as a percentage.

Let us take a closer look at the negative tone of the information environment in the news when the word "Automation" is mentioned. The analysis of the information environment allows us to assess how the tone of the news has changed over time (Rudskaya et al., 2020). The data search algorithm can be divided into 2 stages. The first stage is the formation of the primary data set. At this stage, a news array is collected in accordance with the analyzed time period, from 2005 to 2020. The source of primary information is Google News, as this platform is popular at the Internet. For parsing this data, the programming language Python 3 and the library GoogleNews can be used. With the help of this library, it is possible to cover through a massive amount of news headlines in the period and the language of interest. The second step is to analyze the tone of the received information. At this stage, the collected news headlines are tonally analyzed by three metrics using Dostoevsky library (Veselov, 2018): negative, positive, neutral. The average value for each year is also calculated.

The labor market index is a coefficient calculated on the basis of changes in the indicators characterizing the labor market by country, calculated by the OECD - Organization for Economic Cooperation and Development. It characterizes the labor market state, determined by the job seeker activity level relative to the employer demand. The higher the value of the labor market index, the more favorable the situation is for the employers, as a high value indicates high job seeker activity and low demand from the employers, which ensures finding a qualified specialist easily. The index calculation base is 100. It defines the expected mean value of the normalized index time series with monthly values over five years. A sufficient set of data ensures the representativeness of the sample, as it includes all kinds of data (stable situations, rapid growth, stagnation, and crisis). The index consists of several indicators, which determine the state of the labor market, namely the unemployment rate, the number of unemployed and the wage index. In order to balance mathematical operations with indicators of different nature, we should normalize the time series of each indicator. This index is calculated for each of the countries based on open data.

It must be noted, that while the unemployment rate is used in labor market index calculation, it is also an important indicator on its own. It indicates not just one of the aspects of the labor market, but the consequences of the socioeconomic environment expressed within the labor market. This nature of the indicator determines the contrast of

its impact on the information environment, which is shown in the last considered regression equation. The given set of indicators is aggregated in a single summary table (Table 1).

Table 1 Indicator summary table

Indicator	Designation	Units	Type	Sources
Number of robots per 10000 workers – robotization rate	x1	Coefficient	Exogenous	Robotic Density IFR
ICT index	x2	Factor	Endogenous – exogenous	ICT Index
Government ICT implementation readiness index	v1	Factor	Exogenous	Oxford Insights
Global Innovation Index	v2	Factor	Exogenous	Global Innovation Index
Gross expenditure on R&D	v3	Coefficient	Exogenous	Global Innovation Index
Feasibility of ICT implementation	x3	Factor	Exogenous	Global Innovation Index
Public interest in professions with a high level of automation	y1	Level of interest (points)	Endogenous – exogenous	Google trends, Automation Index
Unemployment rate	y2	%	Exogenous	Macrotrends
Negative tone of information environment in Google News	f1	Coefficient	Endogenous	Dostoevsky
Labor market index	z	Coefficient	Endogenous	OECD

The reliability level is determined at 90% due to data specifics since most model`s indicators are indices and can be similar to each other. Significant level for each indicator should not exceed a value equal to the difference between one and the level of reliability. Therefore, each characteristic-factors with a value greater than 0.1, will be excluded from the model one by one, since they will not affect the result-factors. There is no specific value of R2 for this model that will be acceptable as well as approximation error.

3. Results and Discussion

According to the results of the regression analysis, the indicators of robotization rate and the feasibility of introducing ICT were removed from the model. These indicators do not have a significant impact on the result of modeling. The results of regression analysis for each equation are shown in Table 2.

Table 2 Regression results

	Multiple R	R-squared	Adjusted R-squared	Standard error	*Coeff.*	*t-statistics*	*P-value*
Equation 1	0.7926	0.6282	0.5268	0.3096			
Intercept				0.7778	5.6843	7.3135	1.52E-05
$v_{3(t-1)}$				0.0201	-0.0371	-1.8418	0.0926
$v_{3(t-2)}$				0.0221	0.0529	1.9418	0,.782
$v_{2(t-2)}$				0.0153	0.0428	2.8011	0.0172
Equation 2	0.9368	0.8777	0.8427	0.1997			
Intercept				0.2963	16.5771	55.9538	1.53E-10
x_2				0.0502	-0.1607	-3.1979	0.0151
x_1				0.0026	-0.0075	-2.5025	0.0408
Equation 3	0.8571	0.7346	0.6938	0.0306			
Intercept				0.0471	0.0247	0.5232	0.6096
x_1				1.1702	-4.1199	-3.5205	0.0038
x_2				0.0039	0.0227	5.8479	5.71E-05
Equation 4	0.9317	0.8681	0.8516	0.1584			
Intercept				1.6562	-3.8176	-2.3049	0.0501
x_2				0.0166	0.12033	7.2564	8.75E-05

Due to the study limitations, while the regression equations (1) and (2) are valid for all the 15 considered countries, the model including the negative tone of the information environment indicator, was only calculated for Russia. This is caused by both limitations in data collection toolset and the fact that it's impossible to reliably evaluate the tone for a country's information environment without knowing the specifics of said environment, that country's culture and language. The validated conceptual model is presented in Figure 2.

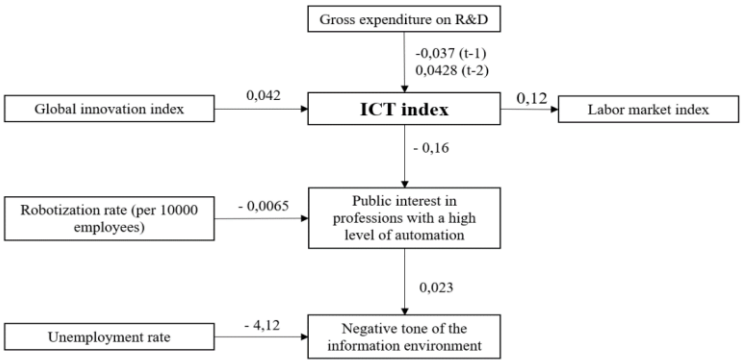

Figure 2 Validated conceptual model of the study

The following regression equations described this system of relations:

$$x_2 = 5{,}68 + 0{,}043 * v_{2(t-2)} - 0{,}037 * v_{3(t-1)} + 0{,}05 * v_{3(t-2)} \quad (1)$$

$$y_1 = 16{,}58 - 0{,}0065 * x_1 - 0{,}16 * x_2 \quad (2)$$

$$f = 0{,}025 - 4{,}12 * x_1 + 0{,}023 * x_2 \quad (3)$$

$$z = -3{,}82 + 0{,}12 * x_2 \quad (4)$$

Based on system of equations we should indicate each result:

1. First equation. As the innovation index increases, the ICT index also increases. The innovation index is a combination of factors that determine a country's position in technological sophistication which are calculated according to established methodology Global Innovation Index. This index includes, among others, the political environment of the country, the presence of a business-friendly environment, various indicators of education, Internet accessibility for the population, availability of electronics, market development, and business and government contribution to research. So, when there is a favorable political environment that motivates and promotes the implementation of information technologies in all spheres of human life, the level of use of these technologies, which is reflected in the ICT index, increases.

The effect of government interest, which is expressed in R&D expenditure, on the ICT index has a negative regression coefficient, but this does not mean that when expenditure increases, the index decreases. In this case, the coefficient is negative because the impact has a time lag of more than one year. This proves the positive value of the index in period (t-2).

The impact of the innovation index and R&D expenditure on the ICT index was examined at the metalevel. No explicit development and dependence of the analytical criteria was found in the period under consideration in the analyzed countries. Stable fluctuations around a central value are present. It can be connected to influences of other factors which have not been analyzed in this example. It is recommended to take a larger sample of countries for further study. Since the relationship is rather weak, it is not useful to change these factors to influence on the outcome, the ICT index. It is necessary to analyze the resulting indicator and its components in more detail in order to develop a more robust model with stronger relationships. Also there is a significant time lag between the allocation of resources for R&D and the changes in the ICT index which should be taken into account in process of results interpretation.

2. Second equation. The effect of the ICT index on the population's interest in professions with a high level of automation has a negative regression coefficient. When the ICT index increases, the interest decreases, which is logical. The value of the coefficient is less than 1, i.e. the strength of influence is low. This may be due to the specifics of the resulting indicator. Population interest is expressed through Google Trends, in scores. Inaccuracies that may have arisen due to the specifics of each language and search queries may have affected the value of the regression coefficient. But nevertheless, the relationship is negative, and its presence is confirmed.

Robotization rate, which is calculated by the number of robots per 10,000 workers, affects on public interest inversely. When robots increase, the interest decreases. The weakness of this relationship, as well as with the relationship to the ICT index, is logically justified by the specifics of the resulting indicator. This relationship is the weakest but at the same time it has a surprisingly low approximation error. The presence of a weak relationship can be justified by the indirect effect on robotization rate on interest in highly automated occupations.

3. Third equation. There is a negative correlation between the population's interest in highly automated occupations and the negative tone of the information environment. If there are decreasing number of searches for vacancies in highly automated professions, then negative tone of the information environment increases. This effect can be shown by negativity appearing in the news in case of "Automation" headline mentioned. The presumed presence of an inverse relationship of these indicators was confirmed. The active process of human replacement by machine labour lead to more negative human perception of ICT development. Examples of occupations that either no longer require human labor or have such a tendency are given in the introduction. People who are left out of work begin to show negative emotions about the cause of their unemployment. Routine occupations tend to replace human labor with machine labor, as stated in the theoretical rationale for the problem. Often, these jobs don't require higher education. For people who have lost their jobs, it is not easy to find a new one in the same field, and finding one in other fields requires requalification, which is difficult. But the value of the regression coefficient is lower than one. This equation was considered on the example of Russia. Information technologies have not yet been implemented in Russia as widely as, for example, in the countries leading in the ICT development index. But even so, the relationship between the indicators is present, though not strong.

The increased level of unemployment lead to decreasing negative tone at the mentioning of the word "Automation". The illogical presence of a negative, relatively strong regression coefficient may be justified by the fact that this dependence has been considered only in the Russian market. First, automation has not come to the Russian labor market widely enough, and there is no mass unemployment associated with it. Second, unemployment is affected by many factors unrelated to the development of technology: seasonality, crises, negative political environment, pandemics, high birth rate and so on. Over time, the relationship between the unemployment rate and negative attitudes towards automation may increase, but this requires a more detailed analysis of the problem.

4. Fourth equation. The impact of the ICT index on the labor market index has a positive regression coefficient, because when the ICT index increases, the labor market index also increases. The relationship is not strong, but still present. This suggests that information and communication technology development does affect on the labor market, what can be expressed by labor market index changing. The presence of a weak correlation can be justified by the fact that the labor market is influenced by many other factors, the development of information technology being just one of them. In general, the presence of

the relationship confirms the impact of the factor on the result. For a more detailed analysis, it may be worth considering a multiple regression rather than a pairwise regression, where the labor market is affected by many factors related to the development of technology.

4. Conclusions

The paper studies the influence of information and communication technologies (ICT) on the transformation of the labor market. Several cases of American, European and Russian companies that implement ICT (for example, robotization) to replace routine labor functions are analyzed. The growing popularity of this trend is also proven by search queries analysis in the Google Trends system (for example, such as Robotic Process Automation) over the past 5-7 years. In all the considered cases, there has been a steady increase in the popularity of queries connected with informatization. At the same time, literature review shows the ambiguity of the impact of the ICT on the development of the labor market from an economic and social point of view, in particular, a number of scholars have proved that such an impact strongly depends on the specifics of industry and the degree of its technological development, as well as the average age of workers involved in the labor market. This research was made for endeavor to prove the information and communication technologies role in the labor market development. The indicators in the model are the Labor market index, the ICT index (consisting of 4 components). The novelty of the study is the introduction into data model for information environment surrounding labor resources. The results of the statistical analysis showed that the ICT index is influenced by the global innovation index and the gross expenditure on R&D. The ICT index, in turn, affects the Labor market index and public interest in professions with a high level of automation. The latter indicator has proven to be related to the tonality of the information environment, aggregating information about workplace automation and measured using sentiment analysis of the news agenda in the Google search engine. The research limitation consists on fact that database partly included results of information environment analysis in the context of subject area. The dynamics of consumer requests in the information environment needs to be constantly monitored, since it can undergo significant transformation due to the influence of many exogenous factors. The directions for further research are the specification of the study by countries and industries (especially in the context of high-tech, mid-tech and low-tech industries), as well as the search and introduction into the model of a larger number of indicators that affect the measured values.

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