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Labor Productivity in the Digital Era: A Spatial-Temporal Analysis

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Abstract. This study examined the role of information and communication technologies (ICT) in labor productivity dynamics. The following ICT components were analyzed: the share of organizations using computers and the share of organizations using the internet. The purpose of the study was to analyze labor productivity in the Russian economy in the context of digital transformation, taking into account two dimensions: temporal and spatial. We investigated the impact of organizations' use of ICT on labor productivity, the relationship between labor productivity and high-tech production, and spatial effects in the dynamics of labor productivity. We used a spatial autoregressive model (SAR) and a panel vector autoregressive model (PVAR) to analyze data for the period 2010–2018. The findings show that digitalization of business processes and an increase in the share of organizations using internet technologies leads to an increase in labor productivity. Certain socioeconomic indicators were also found to be significant, namely, real wages and the percentage of people with higher education in the workforce. Exogenous variables acting as external shocks did not exert significant effects. The results have important implications for managers who develop strategies to increase labor productivity and production efficiency. Such strategies should focus on internetization, business digitalization, and e-commerce.

Keywords: Digital technology; ICT; Labor productivity; Panel VAR model; Spatial model

1. Introduction

Labor productivity is one of the most significant indicators of production companies' efficiency. The task of increasing labor productivity is becoming more complicated for enterprises located in regions with different levels of economic and technological development. In this context, it is of scientific interest to analyze labor productivity in Russia, whose economy has its own characteristics due to its large territory and the uneven economic development of its regions, which include agrarian and industrial-agrarian regions, regions with high economic growth rates, and lagging regions. A consideration of spatial effects allows us to draw a clearer picture of the factors affecting labor productivity.

The rate of change in labor productivity in the period 2008–2018 reflected the economic situation in the world and in Russia: the global economic crisis of 2008–2009 and the geopolitical crisis of 2014–2015 in Russia. Labor productivity in 2009 fell sharply by 4.1% compared to 2008. Nevertheless, the growth rate of labor productivity in the non-crisis years did not exceed 5%, and there is no clear upward trend during this period.

Digital transformation as a factor affecting labor productivity requires thorough scientific scrutiny. Digital transformation entails technological restructuring of economic

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sectors. It enables enterprises to achieve a new level of productivity through the implementation of information and communication technologies (ICT). These technologies increase the speed of business processes, reduce transaction costs, and increase the efficiency of resource use. Russia ranked 45th in the ICT Development Index 2017 and 40th in the IMD World Digital Competitiveness Ranking in 2018.

Several studies have recently raised the issue of digitalization and its impact on various macroeconomic variables (Kolko, 2012; Woodhead and Berawi, 2020). Researchers have investigated the relationships between ICT and inflation, productivity (of all factors), international trade, and economic growth. As a proxy for ICT, researchers often analyze the following indicators: the share of personal computers, the internet, the cost of ICT, and mobile phones. However, studies on the contribution of ICT to labor productivity are scarce and have mainly been conducted at the country level (Shoushtary, 2013; Wiratmadja et al., 2016).

In EU countries, several ICT components have a positive and significant impact on labor productivity. However, the impact of enterprise resource planning (ERP), e-commerce, and customer relationship management (CRM) programs on labor productivity in countries with transition economies is higher than in developed EU countries (Relich, 2017). The positive impact of ICT on labor productivity has also been established for OECD countries (Ceccobelli et al., 2012). The positive effect of ICT on labor productivity is seen for both high-educated and low-educated older workers in Japan and for low-educated older workers in Korea (Lee et al. , 2020).

In the Russian economy, such factors as computerization of workplaces and use of server equipment, mobile subscriber devices, and broadband internet in organizations that require a high degree of automation have been shown to have a significant positive impact (Metlyakhin et al., 2020). Studies on labor productivity in Russia, however, note a downward trend (Abramova and Grishchenko, 2020).

Many studies have attempted to identify factors that affect labor productivity. Employment rates negatively correlate with labor productivity, whereas human and fixed capitals, oil rent, financial development, trade openness and innovation are positively associated with it (Samargandi, 2018). Bakas et al. (2020) used panel data on a sample of 34 OECD countries over a period of three decades and showed a significant positive relationship between cultural past and labor productivity. The main factors of this relationship were control and work ethics, while obedience seemed to negatively affect labor productivity. Access to electricity can also significantly increase labor productivity in the long term (Alam et al., 2018).

Regional factors associated with labor productivity have also been investigated. Zheng et al. (2017) found that the levels of investment, foreign investment, and exports vary significantly across regions. Only human capital, real wages, and firm size are common determinants. A spatial analysis of labor productivity in Germany showed that its main determinants are job and worker characteristics (Fuchs-Schündeln and Izem, 2012). Although East and West German skills are very similar, job characteristics are significantly less favorable in East Germany. A spatial city-level panel data analysis for China showed that most cities are still underdeveloped and must expand to accommodate more labor and increase labor productivity. Significant spatial intercommunions and spatial heterogeneity of urban agglomeration among Chinese cities have also been observed (Chen and Zhou, 2017).

The purpose of this study was to analyze labor productivity in the Russian economy in the context of digital transformation, taking into consideration two dimensions: temporal and spatial. Temporal analysis was performed to answer the following research question:

"How has digital transformation affected labor productivity in the Russian economy over time?" Spatial analysis was performed to answer the following research question: Are there spatial effects in the dynamics of labor productivity? The aim was to identify possible spatial effects that need to be considered when developing strategies for multi-territorial production enterprises. We investigated the impact of digital transformation variables such as the use of personal computers and the internet by firms.

Our study contributes to the literature in the following ways. First, the existing literature on the role of ICT in labor productivity takes gross domestic product as a proxy for labor productivity, which can produce biased estimates. We studied true labor productivity, which allows an assessment of the contribution of the labor factor. Second, our analysis was performed at the regional level, allowing us to take into account spatial differentiation. Labor productivity investigations at this level are quite rare. Third, we focused on the temporal and spatial effects on labor productivity dynamics. To that end, we used spatial autoregressive and panel vector autoregressive models. To our knowledge, this is the first study to use these methods to assess labor productivity using data from the Russian economy. Finally, this study contributes to the literature on the determinants of labor productivity in developing countries. For Russia, this topic is relatively unexplored mainly due to data limitations.

2. Methods

An assessment of the impact of production digitalization on labor productivity is based on the following conceptual model (Figure 1). Digital transformation involves widespread adoption of ICT by organizations. This, in turn, contributes to informatization of the labor process, and in most cases, its automation and robotization, and increases the complexity of the production process. At the same time, digital transformation has spurred a rapid growth of high-tech industries, which has led to a transformation of their production processes. Thus, in the impact of digital transformation on labor productivity, we distinguished two main channels: the distribution and use of infrastructure objects of digital transformation (personal computers and access to the internet) and the growth of high-tech industries as the main subjects of digital production. Therefore, we formulated the following hypotheses:

H_1: The use of ICT by organizations contributes to an increase in labor productivity. This hypothesis is based on the assumption that the digitalization of the production process makes it possible to reduce manual labor and automate a number of business processes.

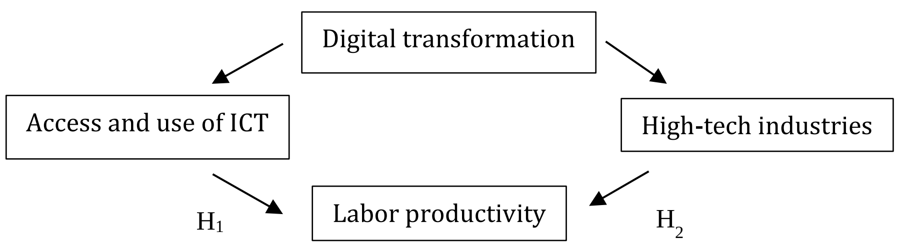

Figure 1 Conceptual model of the channels through which digital transformation affects labor productivity

H_2: A growing share of high-tech industries contributes to an increase in labor productivity. This hypothesis is based on the interconnection and interdependence between

sectors of the economy, where high-tech is a driver of the development of industrial sectors due to the effect of the synergy and diffusion of technologies.

H_3: There are spatial effects on the dynamics of labor productivity. This hypothesis is based on the assumption that the significant differences between Russian regions have significant spatial effects on labor productivity dynamics.

To test our hypotheses, we analyzed data from the Federal State Statistics Service of Russia (Rosstat) for the period from 2010 to 2018. A temporal analysis was performed to determine the main effects of digital transformation on labor productivity. To that end, a PVAR model was employed. Panel data for 83 regions of Russia were used. No data are available for Sevastopol, Republic of Crimea. Table 1 shows the main variables used in the study.

A k-variate PVAR of order p for labor productivity was estimated as follows:

$$lpi_{it} = lpi_{it-1}A_1 + lpi_{it-2}A_2 + \ldots + lpi_{it-p}A_p + pcB_1 + internetB_2 + realwageB_3 + \\ + hightechB_4 + crisisB_5 + educB_6 + u_{it} + e_{it} \quad (1)$$

The following variables were included in the PVAR model as endogenous variables:

1. Labor productivity (*LPI*). This was measured as the growth rate of the labor productivity index. As Chen and Zhou (2017) note, the gross regional product (GRP) that many studies take into account as an indicator of labor productivity includes labor, capital, and total factor productivity combined. Therefore, when measuring true labor productivity, especially in resource and industrial regions, it is subject to significant bias. According to the methodology approved by the Federal Statistical Office (Rosstat Order No. 274, 2018), the labor productivity index for a region's economy is calculated as the quotient of the physical volume indices of the GRP and changes in total labor costs.
2. The share of organizations that used personal computers (*PC*).
3. The share of organizations that used the internet (*internet*).

Table 1 List of variables, their labels, and their definitions

Label	Variable
LPI	Labor productivity index (as a percentage of the previous year's value)
internet	Share of organizations that used the internet
PC	Share of organizations that used personal computers
realwage	Real average monthly wages of employees, as percentages of the previous year
hightech	High-tech industries' share of the gross regional product
crisis	The crisis of 2015 as a dummy variable in the model
educ	Share of people with higher education in the total employed population aged 25–64 years

In Equation 1, A_1, A_2, ... A_p are matrices $k \times k$, B are matrices of dimension $l \times k$, and u_{it} is a vector of dimension $1 \times k$ containing fixed effects of the dependent variable. We selected a model with fixed effects based on the fact that the regions of Russia were relatively stable in their characteristics of economic development during 2010–2018. Finally, e_{it} is a vector of random errors of dimension $1 \times k$ corresponding to the following conditions:

$$\mathrm{E}\left[e_{it}\right] = 0, \mathrm{E}\left[e'_{it}e_{it}\right] = \Sigma, \mathrm{E}\left[e'_{it}e_{is}\right] = 0 \text{ for all } t > s. \quad (2)$$

The following variables were tested as covariates in the model:

1. *Realwage*. The theory of wage efficiency shows that higher real wages can ultimately lead to higher labor productivity by increasing the opportunity costs of job loss. Consequently, the cost of labor leads to the replacement of labor by capital, which increases labor productivity (Wakeford, 2004).
2. *Hightech*. The share of high-tech and knowledge-intensive industries in the GRP is calculated as the quotient of the gross value added of high-tech, medium-tech, and low-tech industries of a constituent entity of the Russian Federation at basic current prices and the GRP of a constituent entity of the Russian Federation at current prices. Since 2017, Russian statistical accounting has used a new All-Russian Classifier of Economic Activities—OKVED-2—for comparison with international statistics. According to the Classifier, high-tech activities include the production of medicines and materials used for medical purposes, the manufacture of computers and electronic and optical products, and the production of aircraft, including spacecraft, and related equipment.
3. The dummy variable *crisis* reflects the geopolitical crisis of 2014–2015 in Russia, which was accompanied by economic sanctions, a slowdown in business activity, a drop in industrial production, a reduction in real wages, and a decrease in labor productivity. Figure 2 shows sharp decreases in the growth rates of labor productivity, wages, personal computers, and internet use in organizations. We observe a slowdown in the dynamics of the share of high-tech products in 2016.
4. *Educ* is a proxy variable for describing the level of human capital.

The main PVAR parameters were evaluated by a generalized method of moments (GMM) estimation using Abrigo and Love's (2015) algorithm. The number of lags in the model was selected based on consistent moment and model selection criteria for GMM models established by Andrews and Lu (2001), the Akaike information criterion, the Bayesian information criterion, the Hannan-Quinn information criterion, and Hansen's J-statistics. The selection of factors was based on the Granger causality test. At the final stage, we calculated the forecast error variance decomposition and the orthogonal impulse response function.

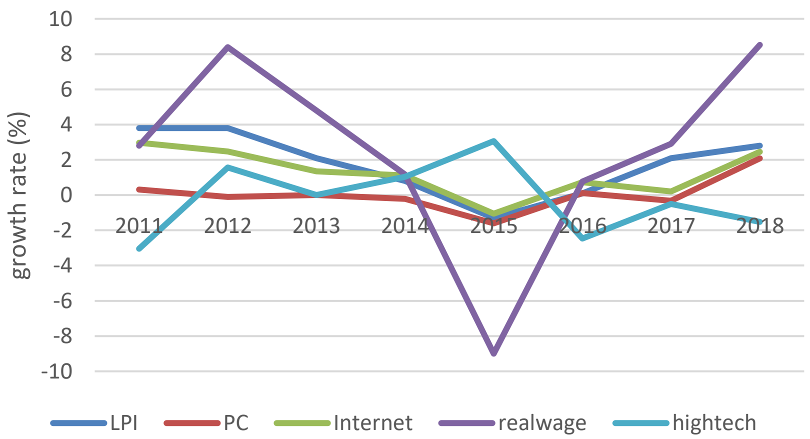

Figure 2 Dynamics of the main variables in 2011–2018

We assessed the presence of spatial effects on labor productivity using the SAR model (Elhorst, 2014) as follows:

$$LPI = X\beta + \rho W * LPI + \varepsilon \tag{3}$$

where X is the matrix of explanatory variables, β is the vector of estimated coefficients for the factors, W is the normalized bounding weight matrix, ε is the perturbation vector, and ρ is the spatial correlation coefficient, whose sign and significance determine the existence or absence of spatial effects.

3. Results and Discussion

3.1. Temporal Analysis of Labor Productivity

The simulation results presented in Table 2 reveal the influence of digital transformation on labor productivity.

The stationarity test according to Pesaran (2007) unit root test for panel data showed that the variables included in the model were stationary. To build a PVAR model of labor productivity based on the model selection criteria of Andrews and Lu (2001), first-order PVAR was selected.

The labor productivity lag was insignificant at the 0.05 level: the value of labor productivity in a year did not affect the following year's value. Based on the PVAR model, it cannot be concluded that the share of high-tech products affected labor productivity. However, the share of organizations using computers was a significant influencing factor.

Table 2 Results of the PVAR model for labor productivity

Variable	Coefficient	Standard Error	z	P > z	95% Confidence Interval	
LPI(-1)	0.0710	0.0446	1.59	0.111	−0.016	0.158
educ	0.0154	0.017	0.92	0.360	−0.018	0.048
crisis	−1.813	0.411	−4.41	0.000	−2.619	−1.008
realwage	−0.005	0.028	−0.18	0.857	−0.060	0.050
hightech	0.0186	0.017	1.12	0.263	−0.014	0.051
PC	−0.141	0.0641	−2.20	0.028	−0.267	−0.015
internet	0.160	0.051	3.14	0.002	0.060	0.259

The Granger causality test revealed the status of the crisis in 2015, the share of companies using computers, and the share of companies using the internet as Granger reasons for labor productivity.

The orthogonal impulse response functions shown in the Appendix revealed a short-term increase in labor productivity in response to shocks caused by other variables and a decrease during the crisis. However, exogenous variables that could act as shocks did not have a significant effect on labor productivity according to the model estimations.

3.2. Spatial Analysis of Labor Productivity

To test our hypothesis regarding the significance of spatial effects on the dynamics of labor productivity (H_3), we used the SAR model. The results are presented in Table 3.

The significance of the "spatial rho" coefficient confirmed the presence of spatial effects in the dynamics of labor productivity. Among the main variables, internet use (*internet*), the share of high-tech industries (*hightech*), and real wages (*realwage*) were significant. An increase in the share of organizations using the internet and an increase in real wages led to an increase in labor productivity. Similar results were obtained by the OECD. An increase in the share of firms using broadband internet was associated with an increase in multifactor productivity (OECD, 2019). On the other hand, an increase in the share of high-tech products in the GRP, taking spatial effects into account, reduced labor productivity.

Real wages and high-tech were the two variables whose growth had a significant positive impact on productivity. These results are consistent with Zheng et al. (2017) and

Dua and Garg (2019), who also found that technological progress and human capital are important factors affecting productivity. For the Russian economy, Tumilevich (2019) demonstrated the role of the percentage of people with higher education in labor productivity.

Table 3 Results of the SAR model for labor productivity

LPI	Coefficient	Standard Error	z	P > z	95% Confidence Interval	
educ	−0.021	0.017	−1.27	0.205	−0.053	0.011
crisis	0.324	0.516	0.63	0.530	−0.688	1.335
realwage	0.124	0.030	4.21	0.000	0.067	0.182
hightech	−0.0867	0.015	−5.91	0.000	−0.116	−0.058
PC	−0.067	0.057	−1.17	0.240	−0.178	0.045
internet	0.095	0.046	2.09	0.037	0.006	0.185
spatial rho	0.238	0.043	5.58	0.000	0.154	0.321

R^2: within = 0.1249; between = 0.1310; overall = 0.1199; Log-likelihood = −1655.6463

The PVAR model confirmed the importance of the use of the internet and personal computers, while SAR confirmed the importance of the internet. In line with these results, Relich (2017) demonstrated the significant positive effect of these ICT parameters on labor productivity, and Metlyakhin et al. (2020) showed the significance of broadband internet.

Additionally, our analysis shows the importance of real wages, which must be taken into account by top corporate managers when developing strategies for increasing labor productivity.

Conversely, our analysis revealed no significant effect of the labor productivity lag. A dependence of a year's labor productivity value on the previous year could not be established. A possible explanation for this is the scale of the data. Since we used annual data, autocorrelation of labor productivity could not be confirmed. Further research is needed to verify any autocorrelation of labor productivity in the short term to determine the time lags in the responses of labor productivity to changes in economic conditions.

The significance of the spatial effect in changes in labor productivity based on data from Russian regions makes it possible to substantiate the differentiation of regions according to the dynamics and level of labor productivity.

The positive impact of organizations' use of the internet on labor productivity provides an argument for the internetization of business processes and the development of electronic business and commerce. At the same time, the negative impact of the increase in the share of organizations using personal computers can be explained by the concept of production functions, according to which a growth of capital not accompanied by a growth of labor can reduce the total volume of production.

4. Conclusions

This study contributes to the assessment of the determinants of labor productivity as one of the main characteristics of production efficiency. Digital transformation affects labor productivity through the implementation and use of ICTs by increasing the physical objects of digital transformation (personal computers in organizations) and the internetization of business processes.

Based on our research results, the following recommendations can be offered. First, when developing strategies for increasing labor productivity in multi-territorial enterprises, top managers should take into account the spatial effects, the interconnection and mutual influences of neighboring regions on the level of labor productivity in a particular region. Second, the importance of ICT and the level of wages, which entail additional costs for enterprises, suggests the need to stimulate private businesses' investment activities.

It can be concluded that the study hypotheses were confirmed. Accordingly, the development of a regional information and communication infrastructure should become a priority for public authorities. Labor productivity can then be increased through the modernization of production, the introduction of high-tech equipment, and the creation of an infrastructure support system.

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Appendix Orthogonalized impulse response functions