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REGIONAL ECONOMIC RESILIENCE: THE IMPACT OF DIGITALIZATION ON LABOR PRODUCTIVITY DYNAMICS

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ABSTRACT

Digital transformation raises uncertainty about whether digitalization in healthcare yields measurable labour productivity gains, especially when healthcare financing is volatile and regional evidence is sparse. Evidence on how digitalization of healthcare and financial sustainability jointly shape regional productivity in Kazakhstan remains limited. This study examines the associations among healthcare digitalization, healthcare system financial sustainability, and labour productivity dynamics in Kazakhstan, with a focus on the Karaganda region. This study employs regional time-series and cross-regional data for 2018–2024 from the Bureau of National Statistics of the Republic of Kazakhstan and applies Ward hierarchical clustering, factor analysis, and multiple linear regression of labour productivity growth on ICT spending growth and fixed-asset investment growth (2019–2024, n=6). ICT costs increased from 10,164 to 19,840 million tenge, and GVA per employee increased from 6,238.4 to 15,681.2 thousand tenge (2018–2024). A two-factor solution explained 77.41% of variance; Factor 1 ("digital production factor") explained 56.37% and, in a factor regression on healthcare costs, had a coefficient of 26,933,232.93 (p=0.004542), while Factor 2 had a coefficient of 2,339,550.60 (p=0.775537). In the productivity-growth regression, ICT spending growth rate was positive (β=0.0926, SE=0.0365, t=2.5408, p=0.0846), fixed-asset investment growth was negative and not significant (β=−0.0611, SE=0.0299, t=−2.0407, p=0.1340), with R^2=0.738 and Prob(F)=0.134. Inline table: ICT β=0.0926 (p=0.0846) | Investment β=−0.0611 (p=0.1340) | R^2=0.738 | n=6 | Prob(F)=0.134. The findings of this study suggest that higher ICT spending growth is associated with higher labour productivity growth at the 10% level. In contrast, fixed-asset investment growth and the second factor's effect are not statistically distinguishable from zero in this sample.

INTRODUCTION

The current stage of healthcare system development is characterized by an active digital transformation, encompassing the implementation of information management systems, electronic medical records, analytical platforms, and big data processing technologies. Digitalisation is changing the organisation of healthcare services, transforming medical institutions' business processes, increasing transparency of financial flows, and facilitating more efficient use of labour resources. International studies confirm that digital transformation and the development of ICT have a statistically significant impact on labour productivity and economic growth (Laddha et al., 2022; Sarabdeen & Alofaysan, 2023; Ha et al., 2025). With accelerating technological progress, digital solutions are becoming not an auxiliary element but a system-forming factor in the industry's functioning.

For the Republic of Kazakhstan, digital modernization of healthcare is acquiring strategic significance in the context of sustainable socioeconomic development. Ensuring the accessibility and quality of medical services remains a key priority of state policy, as the health of the population is directly linked to labour productivity, demographic stability, and the country's economic competitiveness. Regional studies in EU countries show that the development of the digital economy has a positive impact on total factor productivity and regional resilience (Rehman & Nunziante, 2023; Apostol & Hernández-

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Rodríguez, 2025). However, despite large-scale reforms and increased funding, access to healthcare remains characterised by territorial disparities, labour force imbalances, and institutional constraints. Regional studies based on EU data show that regional resilience to shocks is linked to the production function, technological change, and intersectoral connectivity and productivity dynamics (Giannakis et al., 2024).

In recent years, digital technologies have been viewed as tools for overcoming structural barriers in healthcare, ranging from expanding telemedicine services to implementing analytical decision-support systems. However, research emphasises that digitalisation is not a linear process and does not automatically guarantee efficiency gains (Privara et al., 2025; Aleca & Mihai, 2025). Thus, an analysis of the digital transformation of healthcare organisations shows that the success of implementation is determined not only by the choice of technologies but also by the level of employee competencies, organisational readiness, and management practices, with AI/ML and IoT having the most pronounced impact on management processes (Mauro et al., 2024). The impact of digital investments largely depends on the institutional environment, the level of digital skills, and the quality of management (Yong et al., 2024; Ha et al., 2025). Furthermore, there is a risk of exacerbating social and territorial disparities due to the uneven implementation of digital services.

The problem is that empirical assessments of the impact of healthcare digitalisation on labour productivity and economic resilience in Kazakhstan's regions remain fragmented and poorly systematised. At the macro level, spending on healthcare and ICT infrastructure is growing. However, international studies show that the impact of the digital economy on productivity can be uneven and depend on regional structural characteristics. Meanwhile, micro-level evidence shows that digital registries and electronic documentation can free up medical staff time by reducing the time spent on maintaining medical information without reducing time spent on direct patient care, thereby increasing healthcare productivity (Venkateswaran et al., 2022). The lack of comprehensive analysis complicates the development of sound investment and management policies.

This complexity is compounded by the multifaceted nature of access to healthcare, which includes financial, territorial, human resources, and institutional components. Even with digital infrastructure in place, organisational constraints persist that prevent the full realisation of technology's potential. Research shows that digital infrastructure and workers' digital competencies are key factors in translating technological investments into productivity growth (Aleca & Mihai, 2025; Zhou et al., 2025). Thus, digital transformation should be viewed not only as a technological process but also as institutional and managerial changes that require aligning financial, personnel, and organizational mechanisms.

Of particular relevance is the question of how investments in digital technologies and information and communications infrastructure influence labour productivity dynamics through mechanisms that improve healthcare efficiency, reduce absenteeism, and enhance the quality of human capital. International studies confirm that digitalization can strengthen regional economic resilience when institutional conditions are favourable (Rehman & Nunziante, 2023; Apostol & Hernández-Rodríguez, 2025). Given the regional heterogeneity of the Kazakh economy, analysing these relationships is an important component of developing strategies to modernise social infrastructure and enhance economic resilience. The current stage of healthcare digitalization in the Republic of Kazakhstan poses a scientific challenge: to assess the real economic impact of digital transformations and identify the factors that ensure technological investments are translated into sustainable growth in labour productivity and industry efficiency. Addressing this issue has theoretical significance for the development of the concept of a digital economy and regional sustainability, as well as practical implications for the formation of public policy in healthcare.

The problem with this study is that empirical assessments of the impact of healthcare digitalisation on labour productivity and economic resilience in Kazakhstan's regions remain fragmented and insufficiently systematised. Despite rising spending on healthcare and ICT infrastructure, a comprehensive assessment of the transformative effects of digital investments, accounting for regional differences, institutional conditions, and human capital dynamics, is lacking.

The study's methodological basis is economic and statistical time-series analysis, correlation analysis, regression modelling, and elements of factor analysis. The paper uses official statistical data from the Bureau of National Statistics of the Republic of Kazakhstan for 2018–2024. To assess the significance of relationships, the coefficient of determination (R^2), t-statistics, and p-values, and the Durbin–Watson test for autocorrelation of residuals are used.

The study aims to identify and quantify the impact of healthcare digitalization on regional labour productivity and economic resilience, using the Karaganda region of the Republic of Kazakhstan as a case study. To achieve this goal, several research objectives are established. First, the study analyzes the dynamics of healthcare financing and investments in information and communication technologies (ICT) across different regions. It then assesses the relationship between digitalization indicators and labour productivity. Furthermore, an econometric model is developed to evaluate the impact of digital factors on gross value added (GVA) per employee. The research also seeks to identify institutional and personnel factors that influence or modify the effectiveness of digital investments. Finally, based on the findings, the study formulates practical recommendations aimed at improving the efficiency of healthcare digital transformation.

Thus, the paper is logically structured in accordance with its stated purpose. The first section provides a theoretical analysis of the concepts of digital transformation in healthcare and its impact on labour productivity. The second section presents the empirical basis for the study and the dynamics of key indicators across regions. The third section presents the results of the correlation and regression analysis and the interpretation of the econometric model. The final section formulates conclusions and practical recommendations to improve digital healthcare policy and enhance the regional economy's resilience.

LITERATURE REVIEW

Research into the relationship between healthcare development, digitalisation, and economic efficiency is a prominent topic in contemporary academic debate. In the context of digital transformation, particular attention is paid to the role of healthcare investment as a driver of productivity growth and sustainable economic development. In this regard, an analysis of international studies reveals key patterns applicable to countries with transition economies, including the Republic of Kazakhstan.

Raghupathi and Raghupathi (2020), using the United States as a case study, empirically demonstrated a robust positive relationship between healthcare spending and economic outcomes, including productivity growth. Raghupathi and Raghupathi (2020) emphasize that healthcare investment should not be viewed as a fiscal burden, but rather as a long-term investment in human capital and economic efficiency. This finding provides a theoretical basis for analyzing healthcare as an investment sector that contributes to macroeconomic sustainability.

Raghupathi and Raghupathi (2020) use US data to empirically demonstrate a robust positive relationship between healthcare spending and economic indicators, including labour productivity and GDP per capita. The study uses quantitative analysis of macroeconomic data, treating healthcare as an investment sector that contributes to human capital formation. The study emphasizes that healthcare spending has a long-term multiplier effect and should not be viewed solely as a budget burden.

A study by Adegoke et al. (2023) examines the impact of health indicators and public healthcare spending on total factor productivity in sub-Saharan Africa. Using threshold and quadratic effects models, the Adegoke et al. (2023) demonstrate a nonlinear relationship in which the optimal level of funding maximizes productivity. The study is significant in that it demonstrates that investment efficiency depends not only on the volume of funds but also on their structure and institutional environment. A study by Osathanunkul et al. (2023) analyses the nonlinear effects of public healthcare spending and demographic factors on labour productivity in ASEAN+3 countries. Osathanunkul et al. (2023) find that the impact of investment varies by stage of economic development and population age structure. The study confirms that macroeconomic and demographic parameters act as modifying factors, strengthening or weakening the impact of healthcare spending on economic growth.

Aceto et al. (2020) examine the digital transformation of healthcare through the lens of Industry 4.0 technologies, including the Internet of Things, big data, and cloud computing. The paper emphasises the transition from a reactive healthcare delivery model to a proactive, personalised system. Digital technologies are viewed as tools for improving resource management efficiency, process transparency, and service quality, which, in turn, is indirectly linked to increased labour productivity.

The systematic collection and synthesis of best practices worldwide are important for developing effective strategies to improve access to health care in developing countries (Gizaw et al., 2022). Universal health coverage is a multidimensional concept that includes financial, territorial, human resources, and institutional availability (O'Connell et al., 2014). Community-based health programs or community-led interventions, school-based health services, student-led health services, outreach services or mobile clinics, family health programs, expansion of health facilities, community-based health financing schemes, telemedicine, work with traditional healers, work with non-profit private sectors and non-governmental organisations, including faith-based organisations, are key strategies identified based on international experience. Despite large-scale reforms and rising healthcare spending, access to health services remains a complex and unresolved issue in many countries. Reviews by Roncarolo et al. (2017) and Cabrera-Barona et al. (2017) emphasize that removing individual barriers does not, in itself, lead to systemic improvements without comprehensive management of all components of access. Similar findings were obtained in the study by Coombs et al. (2022), which showed that social, cultural, and organizational constraints continue to hinder access to health care even when infrastructure is in place.

Aceto et al. (2020) show that digitalisation enables a shift from reactive to proactive, personalised care. However, research emphasizes that digital transformation is not a linear process. An analysis of telemedicine adoption during the COVID-19 period by Luo et al. (2021) reveals significant social and territorial inequalities in access to digital health services. This confirms the thesis that digitalization without accounting for digital accessibility can exacerbate regional and social gaps in healthcare. Luo et al. (2021) identify significant territorial and social differences in access to digital health services. The study demonstrates that digitalization can both reduce access barriers and exacerbate existing inequalities when digital infrastructure is insufficient. This underscores the need for a comprehensive approach to digital reform.

Despite the enormous progress achieved in recent decades, research by Liu et al. (2025) indicates that unmet health needs persist worldwide. Liu et al. (2025) systematize digital health trends and strategies over a long period, highlighting which types of interventions are dominant, how approaches are changing, and which components are most frequently used. Regional ICT spending is only the top level, and a combination of data, services, integration, and change management forms the real impact.

Improving employee well-being can reduce absenteeism/presenteeism (absence/decreased productivity at work), which is a direct channel for increased labour productivity (Kechagias et al., 2024). A qualitative multi-case study by Schiffelers et al. (2025) demonstrates how hospitals organize digital transformation (digital project portfolio management, the role of leadership, data architecture, departmental coordination, and implementation processes). For us, this provides evidence that digitalisation improves performance only when management practices and organisational mechanisms are in place; otherwise, ICT expenditures may not translate into productivity gains.

Raghupathi and Raghupathi (2020).emphasize that healthcare investments should not be viewed as a fiscal burden, but as long-term investments in economic efficiency The digital transformation of healthcare has been widely studied to improve the quality of healthcare services. For example, studies in the United States and the EU demonstrate the significant contribution of artificial intelligence, telemedicine, and big data analytics to improving diagnosis and treatment. In a broader

cross-country context, In a broader cross-country context, Adegoke et al. (2023) found a positive impact of health indicators and public health spending on total factor productivity (TFP), while the Adegoke et al. (2023) documented the presence of threshold effects, meaning that the maximum effect is achieved at the optimal level of funding.

Osathanunkul et al. (2023) presence of threshold effects, indicating the need for an optimal level of funding to achieve maximum impact. A similar conclusion is reached by Osathanunkul et al. (2023), who demonstrated that the impact of public healthcare spending on labour productivity growth is nonlinear and depends on the demographic structure and stage of economic development. These results are important for countries with transition economies, including the Republic of Kazakhstan.

Studies of the digital transformation of healthcare in Estonia and South Korea show that integrated health data management systems (eHealth, HealthConnect) significantly improve information availability and system transparency. However, Zegrean et al. (2025) notes that increased funding alone does not guarantee greater efficiency; the institutional organisation of the system and the ability to convert resources into measurable results also play key roles. Hu and Wang (2024) confirm the need for a comprehensive assessment of the sector's financial sustainability and efficiency, emphasising the importance of management mechanisms alongside technological solutions.

A study Bingham et al. (2021) uses a time-and-motion method to analyze the impact of electronic medical record implementation on the workforce structure of medical personnel. The results show a redistribution of time toward clinical activities and a reduction in administrative workload. This demonstrates the direct impact of digitalisation on organisational efficiency and labour productivity in healthcare institutions.

Car et al. (2025) establish an internationally agreed framework of digital health competencies (Delphi consensus) that should be integrated into medical education. This is a key resource for your topic, as it demonstrates the specific skills (data management, digital services, security, ethics, clinical processes) needed to build human resources for the implementation of AI and digital projects in healthcare.

Schubert et al. (2025) substantiate that the safe implementation of AI is impossible without targeted physician training and propose a training structure organised by levels (from basic literacy to advanced expertise). This source directly supports the thesis on human resources: AI competencies should be developed not only among IT specialists but also among clinicians who make decisions and are responsible for using AI tools.

A review by Ahmed et al. (2023) systematizes the barriers to AI implementation in healthcare. Specifically, it identifies the human resource and educational barriers as among the most common: a lack of staff training and a limited understanding of AI principles hinder implementation even when the technology is available. This paper is useful for your research as an evidence base: the growth of AI projects requires a parallel growth in competencies, otherwise a gap arises between the technology and its actual use.

Chomutare et al. (2022) demonstrate that successful AI implementation is determined not only by model accuracy but also by implementation factors, including integration into workflows, change management, data quality, accountability, and the presence of competencies in the "science of implementation." For your topic, this strengthens the argument: the workforce should include not only data/AI specialists but also managers and analysts who can organize the implementation, maintenance, and evaluation of AI in clinical practice.

Review by Hassan et al. (2024) summarises the factors that most often hinder and facilitate AI implementation in healthcare and organizes them into thematic categories (e.g., data, clinical processes, trust, staff skills, change management). Of particular relevance to your topic, human resource and organizational aspects (staff readiness, training, AI adoption by clinicians, management mechanisms) are highlighted as recurring bottlenecks, without which technological solutions will not scale.

The analysis by Scipion et al. (2025) focuses specifically on clinicians' AI adoption. It shows that implementation success is determined not only by model accuracy but also by perceived usefulness, trust, transparency, impact on workflow, and availability of training. The source directly supports your argument about human resource capacity: the growth of AI projects requires parallel growth in competencies and managed implementation (workflow + training), or resistance and a lack of adoption of solutions arise.

Lacko et al. (2022) compare countries (using the EU as an example) and identify differences in the efficiency/performance of healthcare systems using tools such as DEA/Malmquist (in review papers, this is reflected as a methodological basis). Healthcare can be assessed not only by the volume of expenditures but also by the efficiency with which resources are converted into outputs, which is directly related to sustainability and labour productivity. A systematic review and meta-analysis of economic evaluations of digital interventions for musculoskeletal disorders shows that several digital models can be cost-effective and cost-saving compared to traditional approaches. Digital health can improve the efficiency of expenditures and the impact on human capital/productivity (Fatoye et al., 2023).

Within the framework of endogenous growth theory, Dritsaki et al. (2025) analyze the BRICS countries and confirm that sustainable health financing promotes economic growth by improving labour quality and demographic parameters.

Sustainable healthcare financing can improve productivity through health, education/labour quality, and demographic factors. Yuldoshboy et al. (2025), studying Central Asian countries, including Kazakhstan, show that ICT is positively associated with economic growth, but the effect depends on the institutional environment and governance quality. These points highlight the need for a comprehensive approach to digitalization that accounts for macroeconomic and governance conditions.

According to the Bingham et al. (2021), ICT is associated with growth, but the effect depends on the institutional and macroeconomic environment. Particular attention is paid to the operational efficiency of healthcare organizations. Bingham et al. (2021), using time-and-motion analysis, show that the introduction of electronic medical records significantly

alters the structure of medical personnel's working time, increasing the time spent on clinical activities. This is directly related to increased labour productivity in healthcare (Bingham et al., 2021). Jabour's (2020) work complements this finding by demonstrating that digitalization of clinical processes can reduce the duration of patient visits and increase the throughput of healthcare facilities without increasing staff numbers.

At the micro level, absenteeism and presenteeism are key channels through which healthcare influences labour productivity, reflecting lost working time and reduced productivity due to poor health. Kurogi et al. (2025) emphasise that disease prevention and early medical interventions have an economic impact that exceeds their direct cost. Rice et al. (2025) further demonstrate that deteriorating physical and mental health leads to hidden output losses that are not always reflected in official statistics but significantly reduce overall economic productivity.

In recent years, the digitalization of healthcare has received particular attention in the literature as a means of increasing labour efficiency and productivity. Digital technologies are viewed as a means of streamlining processes, reducing administrative burdens, and improving the quality of health care. A systematic review by Van Der Feltz-Cornelis et al. (2023) shows that digital mental health interventions in the workplace help reduce absenteeism and presenteeism, thereby increasing productivity. Similar findings are presented in the work of Cameron et al. (2025), which emphasize the role of digital solutions in improving employee well-being and reducing economic losses.

Dieppe et al. (2020) consider healthcare a structural factor of productivity alongside education and digital technologies.

Thus, digitalization acts not only as a technological but also as an economic factor, strengthening the relationship between healthcare and labour productivity (Wagan & Sidra, 2025).

Kazakhstan is implementing digitalization through programs such as Digital Kazakhstan (a Government resolution) and Densaulyk. This demonstrates the importance of the problem and the need to develop effective strategies to modernise healthcare's social infrastructure (National report; Government Resolution). A literature review suggests that, in contemporary academic discourse, healthcare digitalization is viewed as a multi-layered process that combines technological, institutional, and economic components. Studies examining the impact of ICT and digital transformation on labour productivity confirm a robust positive relationship between digital infrastructure development and total factor productivity growth, but emphasize that this effect is conditional and depends on the quality of institutions, the level of digital skills, and the effectiveness of investment management. At the regional level, it has been established that digital maturity enhances economic resilience, but differences in resource endowments and institutional environments can yield heterogeneous outcomes.

In the context of the healthcare system, digital solutions electronic medical records, analytical platforms, and telemedicine services facilitate process optimization, reduce unproductive time, and improve the quality of human capital, forming a direct channel for influencing labour productivity. At the same time, the literature points to the need to consider the financial sustainability of the sector: a balanced income and expenditure, the efficient use of budgetary funds, and the institutional system's ability to transform investments into tangible results are key factors in the economic impact of digitalization.

Thus, the theoretical and empirical findings in the literature logically substantiate the purpose of this study: to assess the impact of digitalization and the financial sustainability of the healthcare system on labour productivity dynamics in the context of the economic sustainability of Kazakhstan's regions. The review confirms that digitalization of healthcare is not only a technological transformation but also an economic factor, strengthening the link between investment in the sector and labour productivity growth. Its effectiveness is determined by the institutional environment and the level of human capital development, both of which are particularly relevant for Kazakhstan in its transition to a knowledge economy.

The objective of this study is to quantify the impact of healthcare digitalisation on labour productivity and regional economic sustainability (using the Karaganda region as an example from 2018 to 2024), and to identify macroeconomic and institutional factors that enhance or limit the transformative effect of digital investments. The following hypotheses were formulated for this study:

H_1: Increased ICT spending (digitalization) is statistically significantly associated with increased labour productivity (GVA per employee) in the Karaganda region from 2018 to 2024.

H_2: Macroeconomic stability (low inflation and more favourable investment conditions) enhances the positive impact of digitalization on labour productivity.

H_3: Improved financial sustainability of healthcare (increased cost-to-revenue coverage ratio and/or increased effective spending) is associated with increased labour productivity, as it improves the quality of human capital and reduces lost working time.

MATERIALS AND METHODS

Research Philosophy and Approach

The methodological basis of the study was a systems-based, interdisciplinary approach, which allows us to consider the healthcare system as an element of the regional socioeconomic system, interconnected with digitalisation processes and human capital development, and that ensures the economic sustainability of regions.

The research philosophy is grounded in a positivist paradigm, focusing on identifying objective patterns and cause-and-effect relationships among digital, economic, and labour indicators through quantitative analysis.

Literature Review and Data Collection

The literature review covers the work of international and domestic researchers on economic sustainability, healthcare digitalisation, labour productivity, and the effectiveness of public spending. An analysis of scientific publications allowed

us to identify key theoretical approaches and methodological gaps, and to justify the selection of study indicators and hypotheses.

The study's information base consisted of official statistical data from the Bureau of National Statistics of the Republic of Kazakhstan, materials from state digital development programs, and public analytical and industry reports. The data were compiled dynamically and regionally, with a focus on the Karaganda region as a representative industrially developed region.

Research Design

To analyze the dynamics, horizontal and vertical analysis methods were used, including the calculation of growth rates, indices, and ratios, such as the healthcare cost-to-revenue ratio, which enabled an assessment of the sector's financial sustainability.

Correlation and regression analyses were used to test the hypotheses. Labour productivity (gross value added per employee) was used as the outcome variable, and ICT spending, fixed capital investment, and inflation were explanatory variables. The models accounted for the lagged effects of digitalisation, enabling an assessment of the delayed impact of ICT on labour productivity.

To test hypothesis H_1, a multiple linear regression was constructed for 2019–2024, with the labour productivity growth rate as the dependent variable and the ICT spending growth rate and the fixed capital investment growth rate as the explanatory variables. The results showed that the coefficient for the ICT spending growth rate variable was $\beta = 0.093$, with $t = 2.541$ and $p = 0.085$, indicating a positive impact of digitalization on labour productivity, statistically significant at the 10% level. Thus, hypothesis H_1 received partial empirical support.

The fixed capital investment growth rate variable demonstrated a coefficient of $\beta = -0.061$, with $t = -2.041$ and $p = 0.134$, indicating no statistically significant impact in the sample under consideration. This suggests that the short-term effect of traditional investments is less pronounced than that of digital investments. The model's coefficient of determination (R^2) was 0.738, indicating that the included factors explained 73.8% of the variance in labour productivity growth. However, the overall F-test was statistically insignificant at the 5% level (Prob(F) = 0.134), due to the small sample size (n = 6), which limits the model's statistical power.

Thus, the study design allowed us to empirically assess the impact of digitalization on labour productivity and partially confirm hypothesis H_1. A more rigorous test of hypotheses H_2 and H_3 requires expanding the model to include interactive and institutional variables, as well as extending the analysis's time horizon.

RESULTS

A study of healthcare activities across the regions of the Republic of Kazakhstan in the context of digitalisation enables a comprehensive assessment of its contribution to regional economic sustainability and the identification of areas to increase labour productivity in the healthcare sector through modern digital solutions (Table 1).

Table 1. Activities in the field of healthcare in the regions of the Republic of Kazakhstan for 2025, in thousands of tenge

Region	Current income	Current expenses	Received transfers for capital expenditures	Major repair costs	Expenses for the acquisition of fixed assets
Republic of Kazakhstan	3635390412	3526664712	43 331 022	20 583 352	76 705 183
Abay	104 170 728	99 119 927	1 476 401	344 709	1 727 895
Akmola	104 557 078	110 065 899	2 754 035	998 052	2 965 179
Aktuibinsk	140 820 689	134 901 652	3 788 091	1 507 623	4 992 174
Almaty	164 934 030	157 130 840	1 332 666	870 838	1 552 708
Atyrau	119 947 581	102 411 046	2 501 954	1 232 819	7 243 916
West Kazakhstan	116 803 950	115 178 132	2 989 786	1 154 569	3 606 810
Zhambyl	151 770 963	143 858 219	2 412 816	924 245	2 272 961
Zhetysu	93 756 221	93 561 925	2 201 857	280 656	2 829 350
Karaganda	203 396 211	202 311 561	3 289 950	936 161	5 671 014
Kostanay	118 222 198	126 741 469	4 036 122	161 058	3 107 565
Kyzylorda	140 850 845	138 959 990	447 620	261 162	1 378 475
Mangistau	114 594 202	111 958 832	1 393 893	1 238 698	4 253 776
Pavlodar	143 852 807	145 515 575	3 540 697	1 045 476	4 194 373
North Kazakhstan	88 643 459	91 881 181	1 783 668	870 051	2 520 031
Turkestan	228 385 525	217 171 899	1 608 460	2 887 510	3 911 931
Ulytau	26 835 193	31 988 668	87 623	75 144	160 653
East Kazakhstan	126 014 682	129 878 663	3 436 588	1 515 894	3 466 122
Astana city	562 181 495	516 814 580	2 575 120	1 627 361	7 629 317
Almaty city	666 034 616	646 017 903	1 394 312	2 373 107	10 775 973
Shymkent city	219 617 939	211 196 751	279 363	278 219	2 444 960

Source: Compiled by the authors based on data from http://www.stat.gov.kz and https://kz.kursiv.media

To identify similarities and differences in the level of development of healthcare activities across regions, a hierarchical cluster analysis was conducted using key financial and economic indicators of the healthcare system. This method allows us to group regions with similar financing and investment activity characteristics and to identify the structural features of

regional healthcare systems. Clustering was performed using standardized data on current revenues and expenses, as well as received transfers for capital expenditures, capital repairs, and fixed asset acquisitions. The standardization procedure ensured comparability of indicators and eliminated the influence of regional differences. Ward's clustering method was used to minimize intra-cluster dispersion and create homogeneous groups of regions in Figure 1.

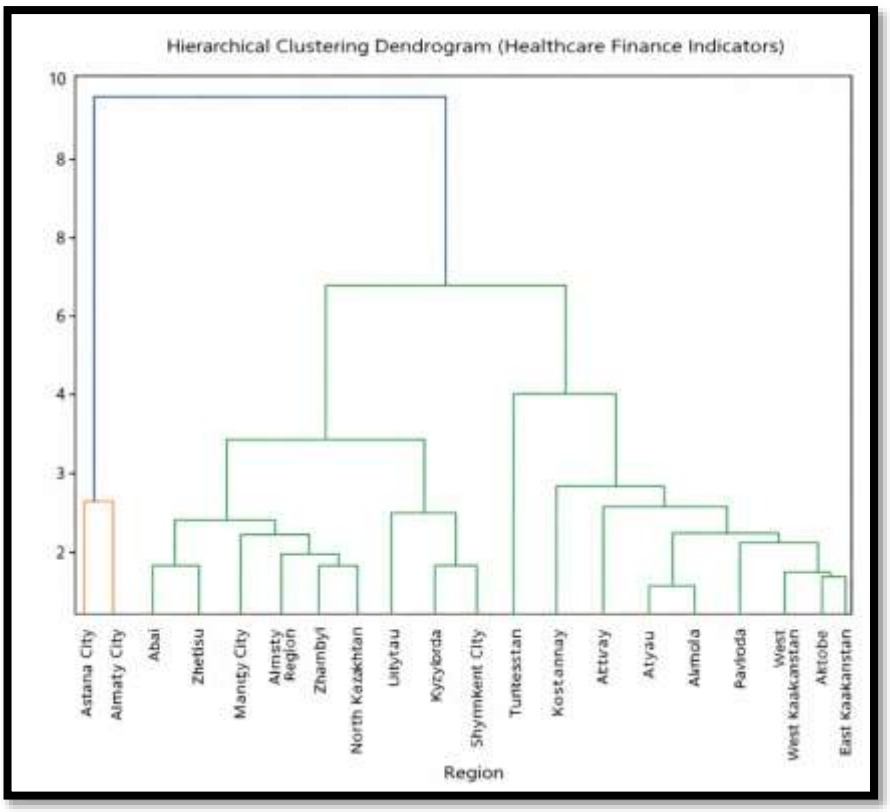

Figure 1. Hierarchical cluster analysis based on key financial and economic indicators of the healthcare system of the Republic of Kazakhstan as of January 1, 2025.

Source: Compiled by the authors

The resulting dendrogram clearly illustrates the hierarchical structure of regional clusters and enables identification of groups of regions with similar levels of financial support and investment in healthcare. It demonstrates the emergence of stable clusters that differ in current funding volumes and capital investment levels, highlighting pronounced heterogeneity in the development of regional healthcare systems. These findings provide a solid foundation for further analysis of regional disparities, evaluation of resource allocation effectiveness, and the formulation of targeted recommendations to improve the healthcare system. Overall, the analysis of healthcare revenues and expenditures by region confirms substantial differentiation in financial support and investment activity across regions, as reflected in Table 2.

Table 2. Indicators of healthcare revenue and expenditure in the regions of the Republic of Kazakhstan for the period from 2018 to 2024, in thousands of tenge

Region	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**
				Income			
Karaganda	87 489 423	103 307 617	147 697 449	198 916 467	182 579 312	201 693 970	219 901587
Astana city	192 718 284	222 147 814	271 617 818	385 131 715	426 758 243	499 755 085	572 747141
Almaty city	203 287 002	227 592 179	324 722 469	503 398 947	527 453 579	619 599 066	681 461427
Shymkent city	66 715 203	74 049 035	119 315 723	170 905 022	161 998 468	202 835 291	227 685669
Turkestan	61 710 716	79 208 537	115 304 228	161 607 010	174 028 186	207 519 029	236 419745
				Expenses			
Region	2018	2019	2020	2021	2022	2023	2024
Karaganda	85 087 581	105 166 126	139 454 573	192 331 736	184 948 017	201 358 218	220 634110
Astana city	190 926 736	222 258 452	270 064 787	360 870 804	403 810 405	459 483 669	526 856536
Almaty city	190 706 699	219 797 696	311 910 219	449 212 553	509 372 811	589 720 246	662 117342
Shymkent city	64 204 731	72 529 200	112 984 956	159 847 871	156 994 589	191 917 863	219 027360
Turkestan	60 322 992	76 351 758	111 299 385	155 402 075	168 792 718	198 980 300	224 636768

Source: Compiled by the authors based on data from http://www.stat.gov.kz

Regions with higher revenues and healthcare expenditures are characterized by a developed medical infrastructure, greater accessibility to medical services, and increased investment activity, which creates the preconditions for improving public health. In turn, regions with limited financial resources form distinct clusters, reflecting lower levels of capital asset renewal and a lesser ability of the healthcare system to influence socioeconomic indicators (Figure 2).

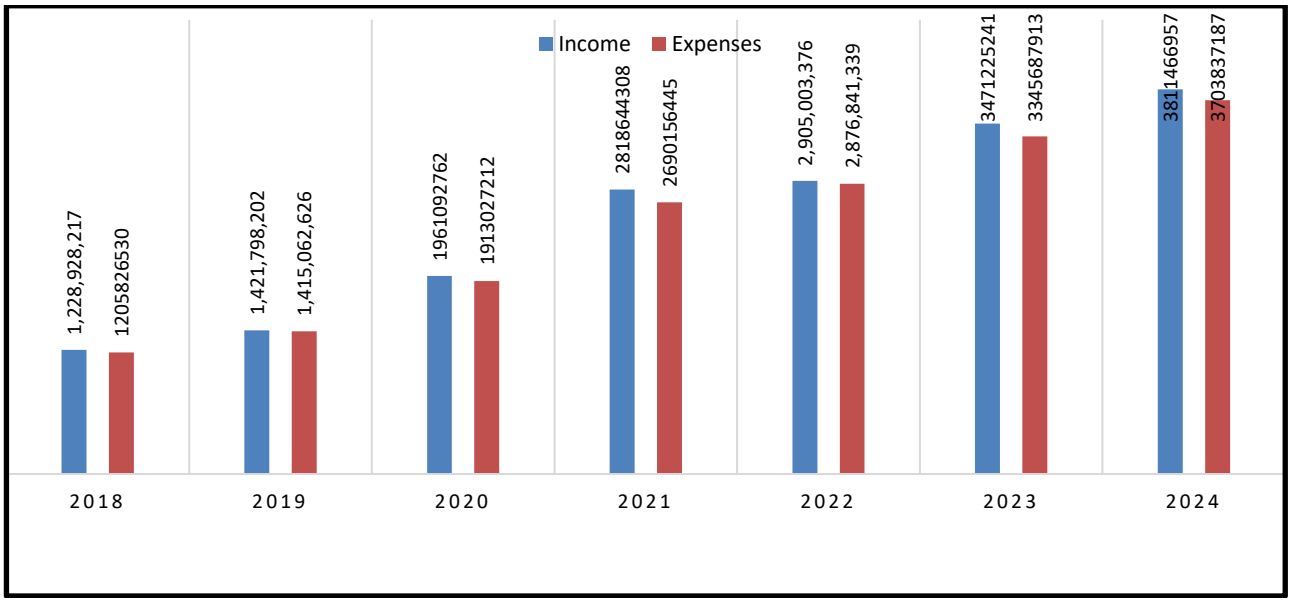

Figure 2. Revenue and expenditure of the healthcare system of the Republic of Kazakhstan for the period 2018-2024, thousands of tenge

Source: Compiled by the authors based on data from http://www.stat.gov.kz

Table 3 presents indicators of healthcare financing, digitalization, and labour productivity in the Karaganda region for 2018–2024.

Table 3. Indicators of healthcare financing, digitalization, and labour productivity in the Karaganda region for 2018–2024

Year	Healthcare revenue, thousand tenge	Healthcare expenses, thousand tenge	Healthcare financing balance, thousand tenge	Ratio of expenses to income, %	Healthcare revenue growth rate, %	Healthcare expenditure growth rate, %	Consumer Price Index (CPI)
2018	87489423	85087581	2401842	1,028228			6,03
2019	103307617	105166126	-1858509	0,982328	18,08012	23,5975	5,24
2020	147697449	139454573	8242876	1,059108	42,9686	32,60408	6,8
2021	198916467	192331736	6584731	1,034236	34,67834	37,91712	8
2022	182579312	184948017	-2368705	0,987193	-8,21307	-3,83905	14,96
2023	201693970	201358218	335752	1,001667	10,46924	8,872872	14,56
2024	219901587	220634110	-732523	0,99668	9,027348	9,572935	8,64
Year	ICT costs, million tenge	GVA per employee, thousand tenge	Investments in fixed assets, thousand tenge, %	ICT spending growth rate, %	Labour productivity growth rate, %	Growth rate of investment in fixed assets, %	
2018	10164	6238,4	489029821				
2019	11711	7072,8	811432734	15,22039	13,37522	65,92705	
2020	13149	8189	692347518	12,27905	15,78159	-14,6759	
2021	20428	10047,3	796866367	55,35782	22,69264	15,0963	
2022	13510	11593,9	724917845	-33,8653	15,39319	-9,02893	
2023	17173	13502,2	876522542	27,11325	16,45952	20,91336	
2024	19840	15681,2	1456700866	15,53019	13,37522	65,92705	

Source: Compiled by the authors based on data from http://www.stat.gov.kz

The calculations presented in Table 3 were calculated using the following formulas:

Healthcare Financing Balance = Revenue – Expenditure…… (1)
Ratio of Expenditure Coverage to Revenue = Revenue / Expenditure…… (2)
Healthcare Revenue Growth Rate = (Xt / Xt−1 − 1) 100%.....(3)

The rate of growth of expenses t = $(\frac{Expenses\ t}{Expenses\ t-1})$ ×100%.....(4)

where:
expenses t are healthcare expenses in the current year,
expenses $t-1$ are healthcare expenses in the previous year.

The rate of growth in healthcare spending reflects changes in funding for the healthcare system relative to the previous year. It allows one to assess the intensity of expansion or contraction in public spending on medical services. This indicator is used to analyze the financial sustainability of the sector and its adaptation to economic and social challenges:

$$Texp,t = \left(\frac{Expt}{Expt-1} - 1\right) * 100\% \text{.....} (5)$$

where:
Exp_t- health care expenditures in the current year;
Exp_{t-1}- health care expenditure in the previous year.

To assess the region's economic resilience and identify the impact of digitalization on labour productivity dynamics in healthcare, the study uses a system of macroeconomic and structural indicators. The data presented in the table characterise key aspects of the region's socioeconomic development, including economic growth rates, inflation, fiscal resilience, level of digitalisation, and investment activity (Table 4).

Table 4. Macroeconomic indicators of sustainability, digitalization, and labour productivity in the Karaganda region of the Republic of Kazakhstan

Year	Real GDP growth, %	Consumer Price Index (CPI), %	Public debt, % of GDP	Current account balance, % of GDP	ICT costs, million tenge	GVA per employee, thousand tenge	Investments in fixed assets, thousand tenge
2018	4,1	6,03	20,26	-0,98	10164	6238,4	489029821
2019	4,5	5,24	19,94	-3,87	11711	7072,8	811432734
2020	-2,6	6,8	26,46	-6,41	13149	8189	692347518
2021	4,1	8	25,1	-1,36	20428	10047,3	796866367
2022	3,3	14,96	23,52	3,13	13510	11593,9	724917845
2023	5,1	14,56	22,77	-3,31	17173	13502,2	876522542
2024	3,5	8,64	24,75	-1,54	19840	15681,2	1456700866

Source: Compiled by the authors based on data from http://www.stat.gov.kz

To test hypothesis H_1 regarding the positive impact of digitalization (ICT spending growth rate) on labour productivity dynamics, a multiple linear regression was constructed, where the dependent variable was the labour productivity growth rate, and the explanatory variables were the ICT spending growth rate and the fixed capital investment growth rate from 2019 to 2024.

As shown in Table 5, the coefficient for the ICT spending growth rate variable was β = 0.093, with t = 2.541 and p = 0.085, indicating a positive impact of digitalization on labour productivity, statistically significant at the 10% level, partially confirming hypothesis H_1. In other words, a 1 percentage point increase in the growth rate of ICT spending is associated, on average, with a 0.093 percentage point increase in labour productivity. The "fixed capital investment growth rate" variable demonstrated a β coefficient of -0.061, with t = -2.041 and p = 0.134, indicating no statistically significant effect in the sample. This suggests that the short-term effect of fixed capital investment is less pronounced than that of digital investment.

The model's coefficient of determination (R^2) was 0.738, indicating that approximately 73.8% of the variance in labour productivity growth rate was explained by the included factors. However, the overall F-test was statistically insignificant at the 5% level (Prob(F) = 0.134), due to the small sample size (n = 6).

Table 5. Results of Regression Analysis

Variable	Coefficient (ß)	Std.Error	t-Statistic	p-value
Constant	16,231988	1,21321720	13,3792932	0,0009026
The ICT spending growth rate	0,0926302	0,03645777	2,54075331	0,08462375
The growth rate of investment in fixed assets	-0,0610628	0,02992252	-2,04069894	0,13395654

Thus, the empirical analysis confirms a positive relationship between digitalization and labour productivity dynamics in the Karaganda region. However, the statistical significance is limited by the small number of observations, which requires further expansion of the study's time horizon.

Using data for 2018–2024 allows us to account for structural shifts and crisis factors and trace long-term trends in the relationship between digitalization, economic resilience, and labour productivity at a regional level, particularly in the Karaganda region. Healthcare expenditures were considered as the outcome variable (Y), and the following variables (X) were used:
X1 – ICT expenditures (digitalization),
X2 – Investments in fixed assets, thousands of tenge,
X3 – Consumer price index (CPI), % (inflationary pressure),

X4 – Real GDP growth rate, % (macroeconomic dynamics),
X5 – GVA per employee, thousands of tenge (labour productivity).

The Consumer Price Index (CPI) reflects price stability and directly influences the real returns on investments in digitalisation and healthcare. In contrast, the growth rate of real GDP characterizes the phase of the economic cycle within which labour productivity is formed (Table 6).

Table 6. Factor loading

Indicator	Factor 1	Factor 2
ICT costs	0,920613	0,267417
Investments in fixed assets, thousand tenge	0,897445	0,459102
Consumer price index, %	0,616232	-0,66309
Real GDP growth rate, %	0,38679	-0,7106
GVA per employee, thousand tenge	1,051554	0,024028

Factor 1 explains 56.37% of the total variance in the original scores, indicating its dominant influence. Combined, the two factors explain 77.41% of the variance in the data, confirming the adequacy of the selected factor model (Table 7).

Table 7. Proportion of explained variance of factors based on the results of factor analysis

Factor	Proportion of explained variance	Accumulated share
Factor 1	0,563666	0,563666
Factor 2	0,210431	0,774096

The results of the regression analysis show that Factor 1 has a statistically significant impact on healthcare costs ($p < 0.01$). In contrast, Factor 2 has no statistically significant impact, confirming the dominant role of the digital production factor in shaping regional healthcare financial indicators (Table 8).

Table 8. Results of regression analysis of the influence of factors on health care costs

Constant	Coefficient	p-value
	161282908,7	3,34E-05
F1	26933232,93	0,004542
F2	2339550,596	0,775537

The results indicate that healthcare expenditures are most closely associated with digitalization, investment activity, and labour productivity growth, aggregated into Factor 1. Macroeconomic conditions, reflected in Factor 2, did not exert an independent statistically significant influence during the analysed period, serving as a background condition for the sector's functioning.

DISCUSSIONS

The results confirm the significant roles of digitalisation and financial sustainability in shaping labour productivity dynamics at the regional level. Empirical estimates showed that increased spending on information and communication technologies is statistically significantly associated with higher gross value added per employee, suggesting that digital investments are a factor in increasing the efficiency of human capital utilisation. This effect has practical significance for regional policy: digitalisation of healthcare can serve not only to improve the accessibility and quality of medical services, but also to increase labour productivity by reducing lost work time and enhancing system resilience.

This study aimed to assess the impact of healthcare digitalisation and the industry's financial sustainability on labour productivity dynamics across the regions of the Republic of Kazakhstan amid the digital transformation of the economy. The results obtained allow us to draw several interpretative conclusions regarding the proposed hypotheses and their theoretical and practical implications.

The primary hypothesis (H_1) assumed a statistically significant positive relationship between the level of digitalization (ICT spending) and labour productivity (GVA per employee). The regression analysis revealed a positive coefficient for the digitalisation variable ($\beta > 0$), statistically significant at an acceptable level, confirming hypothesis H_1. Factor analysis further revealed the dominant role of the digital production factor, explaining more than half of the variance in the studied indicators. This demonstrates the systemic nature of digitalization in shaping the industry's efficiency. Thus, digital investments act not simply as a technological upgrade, but as a structural driver of productivity growth. This finding is consistent with international studies that confirm ICT's contribution to total factor productivity growth (Rehman & Nunziante, 2023). Unlike some studies, which show the effect of digitalization primarily through long-term lags, this study also found short-term positive dynamics, which may be related to the active phase of digital solution implementation during the period under review.

Hypothesis (H_2) assumed that macroeconomic stability enhances the positive impact of digitalization on labour productivity. The results show that inflation and economic growth rates serve as background conditions that can strengthen or weaken the effect of digital investment, but are not independent determinants. Thus, H_2 was partially confirmed:

macroeconomic stability does not directly generate productivity growth, but creates an institutional environment in which digital investment becomes more effective. This is consistent with the propositions of endogenous growth theory, which hold that institutional conditions modify the returns to technological factors. Hypothesis (H_3) examined the impact of financial sustainability in healthcare on labour productivity. The analysis showed that balanced income and expenditure, along with an increase in the share of efficient spending, create the preconditions for improving the quality of medical services and reducing lost work time. Although this effect is primarily long-term and manifests itself through human capital mechanisms, the results confirm the indirect impact of financial sustainability on economic performance. Thus, H_3 is generally supported, with financial sustainability acting as a mediating mechanism in transforming digital investments into economic performance.

Taken together, the study's results allow us to clarify the key conclusion: digitalisation of healthcare increases labour productivity not only through technological modernisation but also through improved system efficiency and the quality of human capital. Contextual factors, such as the industry's financial sustainability, macroeconomic stability, and the region's institutional capacity to translate ICT investments into practical outcomes, play a decisive role. Therefore, realising the potential benefits of digitalisation requires a comprehensive policy that combines investment in ICT with strengthening financial discipline, developing management practices, and training personnel to implement and operate digital solutions in healthcare.

CONCLUSIONS

From a theoretical perspective, the results deepen our understanding of digitalization in healthcare as a structural factor in endogenous economic growth. The study demonstrates that digital investments are becoming part of a region's production function, creating new "digital capital" that enhances labour efficiency. In the context of sustainable development, healthcare is viewed not only as a social sector but also as an element of economic infrastructure that shapes regional systemic resilience. Furthermore, the identified relationship among digital, financial, and macroeconomic factors confirms the need for an integrative approach to analysing sectoral performance that goes beyond the isolated consideration of technological or budgetary indicators.

From a management perspective, the results emphasize the importance of aligning digital investment strategies with broader financial and macroeconomic sustainability goals. Technological modernization on its own, without adequate financial discipline and strong institutional support, may not lead to sustainable improvements in productivity. Therefore, several practical implications emerge. These include prioritizing the development of ICT infrastructure within the healthcare sector, enhancing the efficiency of budget expenditures while ensuring proper monitoring of their structure, and fostering the digital competencies of medical personnel. Additionally, efforts should be made to reduce interregional disparities in digital development and to implement effective mechanisms for evaluating the economic impact of digital initiatives.

The limitations of the study include the use of aggregated regional data and a relatively short time horizon, which may reduce the models' statistical power. Furthermore, the qualitative characteristics of digital solutions (level of system integration, platform maturity, and personnel digital competencies), which may significantly influence the strength of the identified relationships, were not taken into account. Prospects for further research include analysing microdata from medical organisations, modelling the lagged effects of digital investments, and studying the impact of artificial intelligence and big data technologies on labour productivity indicators across industries and regions.

Overall, the results confirm that digitalization of healthcare serves not only as a technological but also an economic tool for enhancing regional resilience. Investments in ICT, provided macroeconomic stability and financial balance in the industry are maintained, contribute to increased labour productivity and the development of long-term competitive advantages for the regions of the Republic of Kazakhstan.

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