



Digital Capital as a Key Factor in the Development of High-Tech Industries in the Region

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Abstract: The article examines the role of digital capital in shaping the competitiveness of high-tech industries in the region. It proves the need to expand the traditional concept of labor capital intensity by including components of digital capital, capitalized research and development (R&D) expenditures, and characteristics of human capital. It is shown that under conditions of digital transformation, the integration of these factors determines the technological maturity of a region and its ability to achieve sustainable innovative development. A conceptual model of digital capital intensity is proposed, which reflects the synergy between technological, intellectual, and institutional resources. The scientific novelty lies in introducing the concept of digital labor capital intensity as an extended indicator of the technological level of regional high-tech industries, integrating the monetary value of digital capital, capitalized R&D expenditures, and qualitative characteristics of labor resources. Unlike traditional approaches limited to physical assets, this concept more accurately reflects the real productive potential of knowledge-intensive industries in a digital economy. Furthermore, the paper presents, for the first time in synthetic form, the triad of interdependencies – “digital capital – R&D – scientific personnel” – as determinants of the digital capital intensity growth.

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1 INTRODUCTION

In the modern economy, intangible assets – data, software, algorithms, digital platforms, and employee competencies – play an increasingly important role. Their totality is often referred to as digital capital. However, despite the growing recognition of its importance in international academic literature, the domestic economic theory and regional statistics lack a unified conceptual and methodological basis for measuring and integrating it into the system of macroeconomic indicators.

This leads to a systematic underestimation of the real technological potential of regions, especially those dominated by knowledge-intensive industries such as microelectronics, biopharmaceuticals, robotics, and quantum technologies. Traditional indicators, such as labor capital intensity, remain focused mainly on physical assets and fail to reflect the contribution of digital assets and capitalized R&D expenditures. As a result, the assessment of productivity, innovative maturity, and competitiveness of regional economies is distorted.

In the context of global technological competition, sanctions pressure, and the need to ensure technological sovereignty, the task of developing adequate tools for analyzing and managing digital capital at the regional level becomes particularly urgent.

Digital capital acts not as an isolated technical resource but as a multi-component, dynamic, and interdisciplinary phenomenon encompassing technological infrastructure, informational assets, human capital, and institutional practices. Its effective use requires synergy between investments in ICT, human capital development, and the formation of a favorable innovation ecosystem.

Therefore, the theoretical comprehension and operationalization of the concept of digital capital, as well as its integration into the extended concept of digital labor capital intensity, acquire not only scientific but also practical importance for forming effective regional innovation and digital policies aimed at the sustainable development of knowledge-intensive industries in the region and the country as a whole.

2 MATERIALS AND METHODS

The study applied methods of theoretical analysis, systematization, and generalization of scientific literature covering a wide range of disciplines – from economics and statistics to sociology, management, and engineering. The methodological

basis included a comparative analysis of various conceptual approaches to defining and measuring digital capital presented in academic literature. Particular attention was paid to the works of leading scholars in the fields of knowledge economy, digital transformation, and national accounting, including publications (Brynjolfsson et al., 2000; Corrado et al., 2013; Zuboff, 2019) as well as analytical materials from the OECD and documents related to the “Industry 4.0” concept.

To ensure methodological rigor in interpreting digital capital as an economic category, we used principles regulating the capitalization of intangible assets – including software, databases, and R&D results. To identify the structural components of digital capital and their interrelations with production indicators, the method of conceptual modeling was applied. This approach made it possible to synthesize disparate theoretical approaches into an integrated analytical framework. On this basis, we formulated an extended interpretation of the indicator labor capital intensity – as an integrative indicator of digital capital intensity, which considers not only the value of physical fixed assets but also the monetary valuation of digital assets, capitalized R&D expenditures, and qualitative characteristics of labor resources, including the share of scientific and engineering personnel and the level of digital literacy.

The analysis was carried out considering the interdisciplinary nature of the phenomenon of digital capital, which required the integration of methodological principles from economic theory, sociology of digital inequality, management studies, and industrial digital transformation engineering.

Altogether, the applied methods made it possible not only to identify the key dimensions of digital capital but also to justify its role as a systemic factor in the technological development of high-tech industries in the region.

3 RESULTS

3.1 Approaches to the digital capital essence

3.1.1 Digital capital as a component of intangible investment and national wealth

Within the new theory of economic growth and productivity measurement, leading economists consider digital capital as a form of intangible asset

to be included in national accounts. Carol Corrado, Jonathan Haskel и Catherine Jona-Lasinio (2017) define digital capital as “investments in software, databases, and other digital assets used in production for more than one year.” The authors emphasize that underestimating such assets leads to undervaluing productivity, especially in sectors with a high share of ICT. The OECD similarly includes three categories in digital capital:

- acquired and developed software,
- databases,
- investments in cloud and computing platforms.

According to the OECD, these assets should be capitalized and depreciated like physical fixed assets.

3.1.2 Digital capital as human and social capital extension

Sociologists, developing Pierre Bourdieu’s ideas, interpret digital capital as an individual resource encompassing access, skills, and social practices. Ellen J. Helsper (2021) defines it as “digital skills, access to technology, and social practices that enable individuals to convert digital resources into economic and social advantages.”

This approach emphasizes inequality of opportunities: not mere possession of technology but the ability to use it effectively determines social mobility. Similarly, Ragnedda (2017) introduces the term digital capital to describe “a combination of technical skills, cognitive abilities, and cultural competencies required for participation in digital society” [4, p. 89].

3.1.3 Digital capital as an organizational and strategic asset

In innovation management literature, digital capital is viewed as a resource that provides competitive advantage.

Youngjin Yoo, Ola Henfridsson, and Kalle Lyytinen (2010) distinguish three dimensions of digital capital in organizations:

- infrastructural (equipment, networks),
- informational (data, knowledge),
- transformational (ability to digitally reorganize business processes).

They emphasize that the value of digital capital lies not in its availability but in the ability to generate new forms of value through digital innovation.

3.1.4 Digital capital as the basis of platform economy and data extraction

Critical researchers of digital capitalism interpret digital capital through the prism of data exploitation and monopolization. Nick Srnicek (2017) argues that “digital capital in the era of platform capitalism is built on the free labor of users, whose data become raw material for algorithms and a source of profit”.

Similarly, Shoshana Zuboff (2019) introduces the concept of surveillance capitalism, where digital capital is formed through massive collection, analysis, and monetization of behavioral data, creating new forms of economic power.

3.1.5 Digital capital as a factor of productivity and economic growth

Empirical studies often measure digital capital as the contribution of ICT and data to labor productivity. Erik Brynjolfsson and Lorin M. Hitt (2000) showed that ICT investments yield returns only when accompanied by changes in organizational processes, indicating complementarity between digital and human capital. Later, Brynjolfsson, Rock, and Syverson (2021) noted that “the growing contribution of data and algorithms to productivity requires revising traditional models of capital measurement”.

3.1.6 Digital capital as the technological foundation of “Industry 4.0”

In engineering and industrial literature, digital capital is treated as the totality of technologies enabling digital transformation in manufacturing. Kagermann et al. (2013), authors of the Industry 4.0 concept, include industrial IoT, cyber-physical systems, digital twins, and cloud platforms in digital capital, emphasizing their role in creating “smart factories”.

3.2 Theoretical and conceptual model of digital capital: interdisciplinary synthesis and structural components

The preceding review shows that there is no single definition of digital capital in the scientific literature; however, several stable conceptual “lines” can be identified:

- Economic–statistical – as part of national wealth,

- Sociological – as an individual resource of inequality,
- Managerial – as a strategic organizational asset,
- Critical – as a form of exploitation and control,
- Technological – as the foundation of industrial digital transformation.

This multidimensionality reflects the complex nature of digital capital as an interdisciplinary phenomenon that requires integrating methodologies from economics, sociology, management, and engineering for its full understanding.

Based on the literature analysis and the theoretical framework presented above, digital capital may be defined as a multilevel, multi-component, and dynamic resource that combines material and intangible assets, competencies, and infrastructural elements ensuring the creation of economic, social, and innovative value in the digital economy.

Specifically, digital capital is understood as the following interrelated components:

- Technological (infrastructural) component – includes physical and virtual elements of digital infrastructure: equipment (servers, sensors, IIoT devices), telecommunication networks (5G, fiber optics), cloud platforms, data centers, and software used in production or management for more than one year,
- Information-analytical component – covers structured and unstructured data, knowledge bases, machine-learning algorithms, digital twins, simulation models, and other digital artifacts capable of generating economic value through optimization, forecasting, and personalization,
- Human and cognitive capital – includes digital competencies of individuals and teams: the ability to work with data, use ICT tools, develop and adapt digital solutions, as well as the level of digital literacy and culture. In this dimension, digital capital is closely intertwined with human and social capital,
- Organizational-institutional component – reflects the ability of organizations and regions to integrate digital technologies into business processes, transform management models, ensure data and intellectual-property protection, and build ecosystems of cooperation between science, business, and government.

From an economic perspective, within the modern methodology of national accounts, a

significant part of digital capital is subject to capitalization and inclusion among intangible fixed assets alongside traditional physical assets. This makes it possible to regard digital capital as a key determinant of digital labor capital intensity, particularly in high-tech sectors.

Thus, digital capital is not only a collection of “digital assets” but a systemic resource determining the ability of economic agents – from individuals to regions – to adapt, innovate, and compete in conditions of profound digital transformation. Its value lies not in passive possession of technologies but in their effective and strategic use for generating sustainable value.

3.3 Digital capital intensity: the role of digital capital in high-tech industries of the region

At the regional level, high-tech industries such as microelectronics, biopharmaceuticals, additive manufacturing, robotics, quantum computing, and advanced energy systems show a direct and multidimensional dependence of their productivity, innovation activity, and export potential on the accumulated level of digital capital.

This dependence is both quantitative and qualitative: modern high-tech enterprises rely less on traditional production factors (raw materials, cheap labor, physical capacity) and more on intellectual and digital assets that ensure flexibility, scalability, and adaptability of production systems.

First, digital infrastructure – including ultra-broadband telecommunication networks (such as 5G and fiber-optic lines), distributed data centers, cloud and hybrid computing platforms, and the industrial Internet of Things – forms the technical foundation for implementing the principles of Industry 4.0. This infrastructure enables the introduction of digital twins, predictive-maintenance systems, autonomous production cells, and cyber-physical systems that connect the physical and virtual production spaces (Polovyan et al., 2023).

Regions with developed digital infrastructure allow enterprises to shorten design cycles, minimize equipment downtime, and quickly respond to demand changes, directly increasing their global competitiveness.

Second, data generated at all stages of a product’s life cycle – from fundamental research and laboratory testing to serial production and after-sales service – have become a strategic economic resource. Unlike traditional factors, data are inexhaustible and reusable: the same dataset may

simultaneously be used for logistics optimization, machine-learning calibration, consumer-behavior modeling, and technological-risk forecasting.

In high-tech industries, where accuracy and decision-making speed are critical, the quality and accessibility of data determine innovation-cycle pace

Moreover, under increasing regulatory requirements (e.g., in pharmaceuticals or aerospace), data have become integral to certification and audit processes, further enhancing their economic value.

Third, human capital – especially its highly qualified segment: scientists, engineers, data analysts, cybersecurity experts, and AI developers – acts as the key intermediary between digital assets and their practical realization. The presence of a “critical mass” of such professionals in a region creates a knowledge-agglomeration effect, facilitates the formation of innovation clusters, and reduces transaction costs in commercialization of scientific results. It should be stressed that in the digital economy, the value of human capital is determined not so much by formal education as by continuous learning ability, interdisciplinary thinking, and capacity to operate within complex digital environments. Therefore, regions investing in STEM education, reskilling programs, and science-technology universities show a sustained advantage in attracting and retaining high-tech industries.

In this context, the concept of digital labor capital intensity acquires special importance – an expanded interpretation of the traditional indicator that accounts not only for the value of physical fixed assets (buildings, machinery, transport) but also for the contribution of digital capital, capitalized R&D expenditures, and qualitative characteristics of labor resources. According to the System of National Accounts 2008 (SNA 2008), intangible assets created as a result of research and development that generate economic benefits for more than one year are subject to capitalization and inclusion among fixed assets. Such assets include not only patents and licenses but also software, databases, machine-learning algorithms, simulation models, and digital platforms. Similarly, investments in cloud services, enterprise IT systems, and industrial sensor networks are also counted as fixed assets if they meet the criteria of long-term use and economic utility.

Thus, growth in digital-technology and R&D investments directly increases the numerator of the capital-intensity formula – especially relevant for regions where intangible assets constitute 40–60% of total fixed-asset value.

At the same time, population size and, more specifically, the structure of employment by

qualification and sector have a complex, nonlinear influence on digital capital intensity.

Formally, an increase in the number of employees with constant asset value reduces capital intensity. However, in practice, dynamics depend not on labor quantity but quality. Growth in the share of scientific and engineering personnel with digital-technology skills encourages enterprises to invest further in advanced production systems, as such specialists can maximize the return on complex equipment and software. As a result, a positive feedback loop emerges over the long term: rising workforce qualifications → increased investment in digital and intellectual assets → higher capital intensity → greater productivity and wages → influx of new staff.

Hence, regions with high concentrations of research institutes, technology parks, engineering centers, and universities focused on IT, robotics, and biotechnology maintain high levels of digital capital intensity and leading technological growth rates.

It should be emphasized that digital capital does not exist in isolation: it interacts closely with the institutional environment, intellectual-property systems, government-support mechanisms, and global value chains. In particular, R&D expenditures in high-tech sectors are increasingly transformed not into physical prototypes but into digital artifacts – algorithms, virtual models, software modules – that can be instantly replicated and integrated into global platforms. Such assets, once capitalized, not only raise the balance-sheet value of enterprises but also increase their attractiveness to investors and international partners.

Within a regional economy, the digital capital of high-tech industries represents an integrative, multi-component resource combining technological, intellectual, institutional, and infrastructural dimensions. Its level determines not only current enterprise productivity but also their capacity for technological breakthroughs, resilience to external shocks (including sanctions and supply-chain disruptions), and integration into global innovation networks. Consequently, regional policy must move beyond a narrow technical focus on ICT infrastructure development and aim to build a comprehensive digital-innovation ecosystem that includes: support for fundamental and applied research, mechanisms for technology transfer between science and business, modernization of higher and professional education systems, incentives for private investment in intangible assets, and creating a legal environment that protects data and intellectual property. Only such a systemic,

synergistic strategy can create sustainable regional cores of the digital economy capable of generating long-term, knowledge-based growth and ensuring national technological sovereignty.

4 DISCUSSION

The analysis confirms that, under deep economic digitalization, traditional macroeconomic and production indicators such as labor capital intensity require substantial revision to incorporate new forms of capital. Ignoring the contribution of digital capital and intangible assets generated by R&D leads to systematic underestimation of regional technological potential, particularly in knowledge-intensive areas. This distorts the picture of regional inequality and may affect inefficient allocation of public resources.

A debated issue concerns the methodology for valuing digital capital: while physical assets have clear market prices and depreciation rates, the value of data, algorithms, or digital platforms is often conditional or potential. Nevertheless, international practice increasingly recognizes the need to include such assets among fixed capital, confirming the validity of an extended approach to capital-intensity measurement.

A key theoretical conclusion is that population size itself is not a determining factor, whereas the quality of labor resources – especially the share of scientific and engineering personnel – is crucial for effective use of digital capital. This supports the hypothesis of transition from an extensive to an intensive model of growth, where the main resource is not quantity but the quality of knowledge and competencies.

Digital labor capital intensity can thus be considered an integral indicator of regional technological development, reflecting not only investment volume in equipment but also the level of digital maturity, innovation activity, and human capital. To improve this indicator, coordinated policy is required to develop digital infrastructure, stimulate capitalized R&D, and enhance workforce potential through modernization of higher and additional vocational education.

Only such a comprehensive approach will enable regions to secure stable positions in the global digital economy and ensure long-term knowledge- and technology-based growth.

5 CONCLUSIONS

In conclusion it should be stressed that digital capital represents a fundamental, multi-component, and dynamic resource determining the competitiveness, innovation resilience, and technological maturity of high-tech industries at the regional level. An interdisciplinary analysis of international literature and theoretical generalization of empirical data identified four interrelated dimensions of digital capital – technological, information-analytical, human-cognitive, and organizational-institutional – whose combined development forms the basis for a transition to an intensive knowledge- and data-driven growth model.

The key theoretical result is the justification of digital labor capital intensity as an extended macroeconomic indicator capable of adequately reflecting the real technological potential of regions dominated by knowledge-intensive industries. Unlike the traditional indicator limited to the valuation of physical assets, the proposed concept integrates into a single analytical construct the capitalized R&D expenditures, the value of digital assets (software, databases, algorithms, cloud platforms), and qualitative characteristics of labor resources, particularly the share of scientific and engineering personnel. This makes it possible to bridge the methodological gap between the modern structure of production resources and outdated statistical practices – especially relevant under global technological competition and the need for national technological sovereignty. It is stated that digital capital cannot function effectively without synergy between digital-infrastructure development, formation of highly qualified human potential, and creation of a favorable institutional environment that includes mechanisms for intellectual-property protection, technology transfer support, and private-investment stimulation in intangible assets. Thus, regional policy should shift from a narrow technical focus to a systemic strategy for building a holistic digital-innovation ecosystem in which digital capital serves not as an auxiliary instrument but as a central determinant of sustainable economic development, ensuring integration of regions into global value chains and the country's long-term technological independence.

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