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ARCHITECTURE OF UKRAINE'S ECONOMIC RESILIENCE IN WAR AND RECONSTRUCTION: INSTITUTIONAL CONDITIONS FOR SCALING AI

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ABSTRACT

The article examines artificial intelligence (AI) as an infrastructural driver of economic resilience and productivity in Ukraine under conditions of full-scale war and post-war reconstruction. It analyses the institutional and economic conditions that enable AI diffusion across the real sector, its commercialisation as product-based solutions, and integration into export-oriented value chains. The study is based on the premise that AI should be understood not as a separate digital sector, but as a foundational technology shaping long-term competitiveness, productivity, and the capacity of the economy to retain value added. Drawing on recent data on Ukraine's computer services exports, the article demonstrates that technology-intensive activities have maintained relative resilience during wartime shock and continue to serve as a significant source of foreign-exchange earnings. This highlights the macroeconomic importance of the digital sector through its contribution to external balance stability and the preservation of investment capacity under conditions of structural disruption. However, the long-term economic effect of AI does not arise automatically from IT services exports. A key challenge lies in the risk of remaining confined to contract-based service models with limited control over intellectual property and product commercialisation. In this context, the capacity for value capture, retaining income from AI-based products, intellectual property, and scalable technological solutions, becomes critical for sustainable revenue formation and domestic investment resources. The article proposes a seven-element institutional framework for AI development ("data – computing infrastructure – models – products – standards – liability – export") representing a complete value-creation chain. The findings show that coherent governance of data access, computing capacity, trust standards, and liability rules is essential for enabling the commercial deployment of AI solutions, strengthening economic resilience, and supporting the transition toward stable export revenues and product-based income streams in the reconstruction period.

Keywords: artificial intelligence, economic resilience, economic security, post-war reconstruction, total factor productivity (TFP), computer services exports, product (value capture) model, legal framework for AI, compute sovereignty, EU AI Act

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INTRODUCTION

Artificial intelligence (AI) in the contemporary economy increasingly functions not as a distinct digital sector but as a foundational infrastructural technology that determines long-term productivity, competitiveness, and the ability of states to retain value added within global value chains through control over intellectual property, data, techno-legal standards, and compliance procedures. International analytical forecasts indicate the scale of its potential impact: according to PwC, the adoption of AI could increase global GDP by approximately 14% by 2030, while McKinsey estimates a cumulative gain of around 16% (PwC, 2020; Bughin, Seong, Manyika, Chui, Joshi, 2018). At the same time, the critical point is that the economic effect of AI does not arise automatically from the mere availability of technology. It depends on the institutional capacity of the state to ensure technology diffusion, access to data and computing infrastructure, the standardisation of trust, and legal certainty regarding liability and the lifecycle of AI models. In this sense, AI should be understood not as a declarative "innovation breakthrough" but as an instrument of structural modernisation requiring a coherent and comprehensive regulatory architecture.

For Ukraine, this issue acquires particular significance under conditions of full-scale war and post-war reconstruction, when, alongside large-scale destruction, the need grows for technologies capable of supporting the recovery of production, infrastructure, and export capacity. The wartime shock caused a sharp contraction of GDP in 2022 by approximately 30%; however, the digital sector demonstrated relative economic resilience, remaining one of the few stable sources of export revenues (Opendatabot, 2026; Lviv IT Cluster, 2025). According to IT Research Ukraine 2025, computer services account for 12.3% of Ukraine's total exports of goods and services (Lviv IT Cluster, 2025), underscoring the role of technology-intensive sectors as a component of economic security amid physical destruction and wartime logistical constraints.

At the same time, the Ukrainian context is not limited to the service segment of IT exports. A domestic product-oriented and innovation-driven AI ecosystem is already emerging in the country. According to estimates by AI HOUSE and Roosh, Ukraine ranks second in the number of AI companies among Central and Eastern European countries, with more than 243 companies operating within the national jurisdiction that develop AI solutions. The number of AI/ML specialists has increased fivefold over the past decade, reaching approximately 5,200 professionals as of early 2024. The combined valuation of the three largest Ukrainian AI startups exceeds USD 14.5 billion, and two companies (Grammarly and People.ai) have achieved unicorn status (AI HOUSE, 2024). This indicates the presence of an emerging product-innovation core and the potential for transitioning from a contract-based service model of digital exports to product-oriented development.

Thus, the central issue for Ukraine is not "acceleration for the sake of acceleration", but the creation of institutional and legal conditions capable of transforming the technological potential of AI into a sustainable economic effect: increasing productivity in critical reconstruction sectors (demining, construction, and local governance), strengthening economic resilience in a broad sense (including productivity, employment, investment capacity, and external competitiveness, including foreign currency earnings), and enabling a transition from a predominantly service-based model to a product-oriented economy through R&D, intellectual property, and export-ready AI solutions. This necessitates analysing AI as an infrastructure of economic resilience and substantiating a coherent legal framework for its development in the context of Ukraine's post-war reconstruction.

LITERATURE REVIEW

In contemporary economic literature, economic resilience is commonly defined as the capacity of an economy and its financial system to withstand significant shocks and to adapt to long-term structural challenges, including crises, technological change, and demographic transformation (OECD. (n.d.-a; Hallegatte, 2014). This multidimensional concept encompasses not only macroeconomic stability and reconstruction capacity, but also the institutional and technological foundations that determine the adaptive potential of the economic system. In this context, technological capabilities increasingly act as a core component of resilience, shaping productivity, structural transformation, and the ability of economies to function under disruption.

Against this background, AI is increasingly conceptualised as a General Purpose Technology (GPT) capable of transforming production processes, organisational structures, and the mechanisms of productivity formation (Bughin et al., 2018). Unlike sector-specific innovations, GPTs have a systemic character and generate multiplicative effects through diffusion across a wide range of sectors, making them a key driver of long-term economic growth. Firm-level empirical studies confirm a positive relationship between AI adoption and increases in total factor productivity, while emphasising the heterogeneity of this effect. Thus, Wang, Sun, and Xu (2023) identify technological innovation, human capital optimisation, and improved market matching as the principal transmission channels, whereas Zhai and Liu (2023), using AI patents as a proxy for innovative activity, demonstrate that the productivity effect of AI is heterogeneous and more pronounced in large, state-owned, and labour-intensive enterprises. These findings are of particular importance for Ukraine, as the productivity potential of AI may serve as an instrument for accelerating reconstruction under conditions of capital and labour shortages, reducing coordination costs, and improving the efficiency of resource allocation in the real sector.

At the macro level, studies focusing on European countries also identify a positive long-term impact of AI development. Kalai, Becha, and Helali (2024), analysing 30 European countries over the period 2000–2021, find a statistically significant long-run effect: an increase in the composite AI development index is associated with a 0.217% rise in GDP per capita. The authors conclude that AI stimulates economic growth through efficiency gains, economies of scale, and improvements in the quality of goods and services. At the same time, negative shocks to AI adoption exert the opposite effect, highlighting the dependence of economic dynamics on the continuity of technological progress.

Particular attention in the literature is devoted to the question of realising the potential of AI in developing countries, where the technology is often viewed as a possible instrument of "leapfrogging". However, empirical evidence shows that the impact of AI is highly context-dependent and does not arise automatically in the absence of sufficient institutional capacity (Ifeanyi, Nwokoro, Ojiako, 2025). Temerbulatova, Zhidebekkyzy, Sagiyeva, and Ludwiczak (2025), based on panel data for 36 countries over the period 2017–2023, demonstrate that the positive effect of AI development on the Global Innovation Index is selective and depends on the nature of the underlying activity. Scientific publications and entrepreneurial dynamics in the field of AI exhibit a stable, stimulating effect, whereas investment indicators and aggregate ranking metrics produce context-dependent and lagged outcomes. This suggests that AI fosters the emergence of new products and business models only where an adequate institutional and scientific-educational foundation exists, and that its impact varies significantly across countries depending on the quality of institutions and the structure of the economy, thereby necessitating adaptive and differentiated public policy.

Particular attention in contemporary economic literature is devoted to the interaction between AI and the labour market. Despite widespread concerns about the displacement of workers by algorithms, a growing body of empirical research indicates that the impact of AI on employment is predominantly structural, manifesting primarily through the transformation of tasks and changes in workforce composition rather than through direct job losses. Within the framework of the complementarity effect, AI technologies tend to assume routine, standardised, and predictive tasks, while human labour shifts towards more complex cognitive, managerial, and creative functions. Evidence of this mechanism is provided by Yang (2022), based on the electronic industry in Taiwan over the period 2002–2018. The adoption of AI technologies is found to be statistically significantly associated with increases in total factor productivity and overall employment, while simultaneously reshaping the workforce structure by reducing the share of low-skilled labour and increasing demand for highly skilled workers. These findings suggest that the effect of AI operates not through direct labour displacement but through task reallocation and rising skill requirements.

Similar conclusions are reached in the cross-country study by Graetz and Michaels (2018) covering 17 advanced economies, where increased use of industrial robots contributed to higher labour productivity and total factor productivity without a statistically significant decline in overall employment, although it was accompanied by a reduction in the share of low-skilled labour. Thus, automation transforms the structure of employment rather than its absolute level. In this context, Brynjolfsson (Global X ETFs, n.d.) and Rob Thomas (Friskey, 2025) emphasise that the key mechanism through which AI affects the labour market lies not in the direct displacement of workers by technology, but in the growing productivity advantage of those employees and managers who are able to effectively integrate AI into decision-making and organisational processes. Under this logic, competition unfolds not between "humans and machines," but between workers who use AI and those who do not, which directly explains structural shifts in employment and the increasing demand for high-skilled labour.

These findings are consistent with the conceptual approaches of Brynjolfsson and McAfee (2015) and Agrawal, Gans, and Goldfarb (2019), who emphasise that the impact of AI on the labour market is not unidirectional and critically depends on whether the technology is used as a tool of pure automation or as a means of augmenting human labour. Within the task-based framework, Acemoglu and Restrepo (2019) demonstrate that AI reshapes the allocation of tasks between labour and capital, generating differentiated outcomes for workers depending on their skill levels and the availability of new labour-intensive tasks capable of offsetting displacement effects.

At the same time, contemporary empirical research shows growing interest in the factors that determine countries' capacity to develop and scale AI ecosystems. Ojeda-Castro et al. (2025), using the Global AI Index for 62 countries and a PLS-SEM model, demonstrate that the key predictors of innovation in AI are human capital (talent) and technological infrastructure, whereas the operational environment (regulatory and societal context) does not exhibit a statistically significant direct relationship with innovation. At the same time, innovation shows a strong positive association with investment, forming a "chain" of talent/infrastructure – innovation – investment. This highlights that national AI development strategies should primarily focus on building competencies, strengthening the scientific and educational base, and expanding digital infrastructure, while regulatory frameworks should function as instruments for removing barriers and supporting ecosystems rather than as self-sufficient drivers of innovation. At the same time, theoretical research warns that without active industrial and educational policy, the diffusion of AI may reinforce global asymmetries, reducing the relative gains of countries that do not control key technologies, computing resources, and mechanisms for the commercialisation of intellectual property, even amid overall growth in global productivity (Korinek and Stiglitz, 2021). In this sense, the development of AI extends beyond the domain of innovation policy and directly necessitates legal analysis, since without institutional conditions for retaining value added (data, compute, standards, intellectual property, and export capacity), countries risk remaining locked into a dependent service-based model of the digital economy despite high levels of technological activity.

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This shifts the focus to the issue of technological sovereignty in the domains of data and computing infrastructure (AI sovereignty), which defines the boundaries of states' strategic autonomy in AI development (Mügge, 2024; Farrell, Newman, 2019; Kenney, Zysman, 2020). A central mechanism of such infrastructural dependence is the cloud ecosystem, concentrated in the hands of a limited number of global providers that effectively shape the conditions of access to data and digital markets. A specific dimension of this challenge is computed sovereignty, which links technological autonomy to control over data centres, GPUs, and computational capacity (Hawkins, Lehdonvirta, Wu, 2025). For Ukraine, this issue has become particularly acute following the relocation of a significant share of data and digital services to foreign cloud environments, thereby increasing dependence on external jurisdictions and platforms. Accordingly, the development of AI in Ukraine should be viewed not only as a matter of innovation policy but as a component of economic security and the state's technological autonomy.

Despite the extensive body of empirical research, the literature predominantly examines the effects of AI in stable economies and under conditions of gradual digital transformation. By contrast, the functioning of AI as an infrastructural factor of economic resilience in the context of armed conflict and post-war reconstruction remains insufficiently explored, particularly with regard to the foreign-exchange role of the technology sector and the transition from a service-based to a product-oriented model. In this context, the Ukrainian case is especially relevant for integrating productivity-based assessments of AI with an analysis of the institutional and legal mechanisms required for its scaling and export-oriented commercialisation in the post-war period.

AIMS AND OBJECTIVES

The aim of the article is to analyse the institutional architecture for scaling artificial intelligence as a driver of Ukraine's economic resilience in wartime and post-war reconstruction and its role in transforming the financial and economic model of the national economy.

METHODS

The study is based on an interdisciplinary approach combining institutional economics, legal analysis, and elements of empirical macroeconomic research. The methodological logic rests on the conceptualisation of AI as an infrastructural technology capable of influencing productivity, the structural dynamics of the economy, and the institutional conditions of development. The research employs a systems analysis method, allowing AI to be examined as an integrated socio-economic and technological ecosystem; an institutional approach to assess the role of legal and organisational conditions in shaping the economic effects of AI adoption; and a comparative legal method to analyse the regulatory model of the European Union and identify possibilities for its adaptation in Ukraine. The empirical component of the study is based on the analysis of open macroeconomic and sectoral data using descriptive statistics, comparative dynamics, and institutional-economic interpretation. In particular, it draws on balance of payments statistics and data on computer services exports from the National Bank of Ukraine, analytical reports from IT Research Ukraine, AI HOUSE, and Roosh, as well as international scholarly sources addressing the impact of AI on productivity, innovation, and economic growth. The regulatory and legal analysis is conducted using formal-legal, functional, and institutional methods, enabling an assessment of legal regimes for AI development and the formulation of a seven-element legal framework structured as a value-creation chain. The data used are publicly available, and the methods applied correspond to generally accepted approaches in economic and legal analysis, ensuring the reproducibility of the results.

RESULTS

Analytical Section

Ukraine's IT Services Exports (2021–2024) as an Indicator of Foreign-Exchange Resilience

In Ukraine's official statistics, AI is not identified as a separate export sector; therefore, its macroeconomic impact is most appropriately assessed through the dynamics of computer services and IT exports as a whole. This segment serves as a proxy indicator for the scaling of data-driven technologies and the diffusion of AI within the economy.

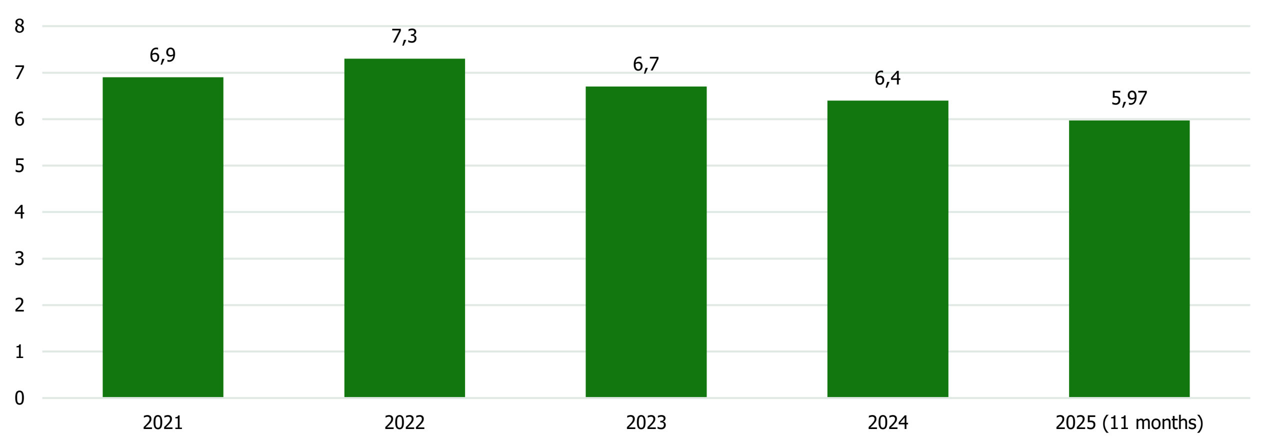

Figure 1. IT services exports, USD billion. *(Source: National Bank of Ukraine; data processing and visualisation – Opendatabot)*

As shown in Figure 1, Ukraine's exports of computer services in 2021–2024 remained relatively resilient even under conditions of full-scale war. Following an increase to a peak level in 2022 (USD 7.3 billion), the sector experienced a correction in 2023–2024 to USD 6.7 billion and USD 6.4 billion respectively, reflecting a phase of stabilisation at a level close to the pre-war benchmark (USD 6.9 billion in 2021) (Opendatabot, 2026; T Ukraine Association, 2023). For the first 11 months of 2025, exports amounted to USD 5.97 billion; although this does not represent a full-year figure, it confirms the continued foreign-exchange role of the sector. This dynamic reflects the structural characteristics of the IT industry, which is less dependent on physical logistics and capable of adapting through remote work formats, team relocation, and rising demand for digital solutions in cybersecurity and dual-use technologies. At the same time, the foreign-exchange role of IT exports remains macroeconomically significant. Computer services constitute the largest category of Ukraine's services exports (exceeding 40%) and function as a foreign-exchange stabiliser under conditions of wartime shock. In this context, the special regulatory regime Diia.City and institutional support for the digital sector (Reutov, Khomenko, n.d.; CEE Legal Matters, n.d.) create the preconditions for a gradual transition from a service-based model towards expanding product and R&D segments with higher value added.

According to Lviv IT Cluster (2025), the technology sector operates as a hybrid model. The service segment ensures short-term foreign-exchange resilience, while product companies and innovation-driven activities generate the potential for long-term value capture and the development of export-oriented technological products. Accordingly, IT services exports should be viewed not only as a source of foreign-exchange earnings but also as an indicator of the structural trajectory of Ukraine's transition towards a high-technology growth model during the reconstruction period. The structural characteristics of the sector are presented in Table 1.

Table 1. Structure of the Ukrainian technology sector (2024–2025). *(Source: based on IT Research Ukraine 2025, AI HOUSE, and Roosh)*

Segment	Verified Indicator	Economic Interpretation
Service model (outsourcing, managed services)	46% of technology companies	Core foreign-exchange stabiliser during wartime; fast contract-based model, low risk, but limited control over intellectual property
Product companies	31% of technology companies	Higher value added, stronger IP control, and potential for product scalability and export
Total IT services exports (2024)	USD 6.45 billion	Key source of foreign-exchange earnings
Share of computer services in services exports	41.9%	The largest component of Ukraine's services exports
Number of companies in Diia.City	3,095 companies, over 130,000 specialists	Institutional base for transition toward product development and R&D
AI companies in Ukraine	Over 243 companies developing AI solutions	Formation of an emerging product-oriented AI core and potential transition toward value capture beyond the service model

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The Role of AI in Monetising the Real Sector (Demining, Construction, Communities)

A widespread perception holds that, in conditions of war and post-war reconstruction, priority should be given exclusively to "physical" tasks – humanitarian demining, infrastructure restoration, and the provision of basic public services, while the development of digital technologies and AI is viewed as secondary or premature. However, such a dichotomy is conceptually flawed. Critical reconstruction tasks and the maintenance of core state functions (humanitarian demining, infrastructure recovery, and community support) require substantial and unavoidable public and donor expenditure, whereas the development of AI, by contrast, has the potential to attract investment and generate scalable, high-value-added products. For this reason, AI should be considered not as a parallel or secondary direction, but as a mechanism capable of increasing the economic return of reconstruction processes and transforming part of the inevitable expenditures into long-term productivity gains and technological revenues derived from the commercialisation of AI solutions.

As contemporary scholarly literature demonstrates, AI is not an alternative to physical reconstruction, but rather a tool for enhancing the efficiency, safety, and economic viability of the very critical processes of the real sector (Dorn, 2019; Hassan, Ahmat, Ouya, 2024). In this sense, AI functions as an infrastructural driver of productivity, capable of reducing the transaction costs of reconstruction and generating value added in sectors that directly determine the economic resilience of the state.

Ukraine today is among the most mine-contaminated countries in the world, and the scale of humanitarian demining objectively exceeds the capacity of traditional, largely manual and technologically outdated methods. Dorn (2019) emphasises that humanitarian demining still relies to a significant extent on mid-twentieth-century technologies, which not only slows the clearance of territories but also creates heightened risks to the lives of deminers and civilians. Under such conditions, the refusal to deploy intelligent systems does not constitute "savings" but rather preserves high costs, prolonged timelines, and human losses. Hassan, Ahmat, and Ouya (2024) demonstrate that integrating AI with unmanned platforms, sensor systems, and digital data analysis methods opens opportunities to improve mine-detection accuracy, reduce false positives, and optimise the stages of technical land surveys. This is not about replacing humans, but about reducing the volume of dangerous physical labour and implementing the principle of machines serving humans, in line with the approach proposed by Dorn (2019).

The economic dimension is equally critical. Humanitarian demining requires substantial and long-term financial resources, whereas digital and AI-based solutions (analytical platforms, decision-support systems) generate value added, are scalable, and possess significant potential for commercialisation and export. Dorn (2019) explicitly identifies technological innovation as one of the key conditions for overcoming the chronic underfunding of demining. Accordingly, the application of AI in this domain should be viewed not only as a security instrument but also as a productivity-enhancing mechanism of reconstruction. Thus, the clearance of territories through intelligent systems constitutes a necessary precondition for the subsequent and far larger-scale process of physical reconstruction of housing, transport networks, and industrial infrastructure.

The scale of destruction in Ukraine, according to international estimates, amounts to approximately USD 486 billion, far exceeding pre-war levels of capital investment and making efficient reconstruction planning critically important (World Bank, 2025). Under such conditions, the application of AI can function as an infrastructural tool for optimising reconstruction processes. First, the integration of AI methods with geoinformation systems and the analysis of satellite and drone data enables more accurate damage assessment, the prioritisation of projects, and the reduction of transaction costs in public decision-making at the community level. Such approaches are widely discussed in contemporary literature as an element of data-driven governance in reconstruction and the management of infrastructure investments (Rawat, Witt, Roumyeh, Lill, 2024). Second, AI algorithms may be applied to model scenarios for allocating scarce resources, assess the socio-economic impact of alternative projects, and improve the efficiency of public investment. However, it remains essential that, in these processes, AI functions as a decision-support system rather than an autonomous governance mechanism, which requires institutional integration, access to high-quality data, and human oversight (OECD, 2019; European Parliament & Council of the European Union, 2024).

A distinct area of AI application in wartime conditions is the enhancement of the management of forced population displacement and social services. Sharmin (2025) demonstrates that AI-based platforms can optimise the allocation of housing, employment programmes, and social services for refugees through the analysis of demographic and socio-economic data. A similar logic is supported by empirical machine-learning approaches used to forecast flows of internally displaced persons in crisis regions (Oishi, Teshima, Akao, et al., 2021). Analytical reports by the OECD and the European Migration Network also document the growing use of digital tools in migration administration, while emphasising the need to preserve human oversight and prevent discriminatory algorithmic practices (OECD, 2019; EMN-OECD, 2022). Likewise, in its ethical guidance, UNHCR considers AI as a means of improving the efficiency of humanitarian services, provided that principles of human rights and non-discrimination are upheld (UNHCR, 2025).

Thus, the examples of humanitarian demining, infrastructure reconstruction, and community governance demonstrate that AI can function as a productivity-enhancing infrastructural layer of the wartime economy. It enables the reduction of coordination costs, accelerates critical recovery processes, and creates the preconditions for the development of scalable digital products with export potential. Ultimately, this strengthens Ukraine's economic security and lays the foundations for long-term productivity growth in the period of post-war reconstruction.

The Risk of the "Service Trap" and the Institutional Conditions for Transitioning to a Product-Oriented AI Model

The global economic effects of AI are increasingly determined not only by the scale of technological adoption but primarily by the capacity of national economies to retain value added and the technological rents generated through the development of AI systems. Contemporary institutional economics emphasises that technological progress in itself does not automatically guarantee welfare gains. What is decisive is the set of formal and informal institutions through which the benefits of innovation are distributed, who controls key assets, and how the structure of economic rents is formed (North, 1990; Acemoglu, Johnson, Robinson, 2005). In this sense, AI should be understood not only as a General Purpose Technology, but also as a source of a new configuration of global inequality, in which advantages tend to concentrate in jurisdictions that control the critical elements of the AI ecosystem.

A central issue in this context is the problem of value capture – the ability of an economy to move from participation in service segments to the creation of proprietary products, control over intellectual property, and the scaling of export-oriented AI solutions. For catching-up economies, there is a risk of becoming locked into a "service trap", whereby digital activity and even substantial volumes of IT services exports do not translate into product ownership and technological rents, but instead reproduce a dependent mode of integration into global value chains (Gereffi, 2018). As Korinek and Stiglitz (2021) emphasise, the diffusion of AI may reinforce asymmetries between centres of innovation-driven income and peripheral economies if the latter do not control the strategic resources of the innovation system.

In the case of AI, this trap has a specific character, as the key mechanisms of value appropriation are concentrated not so much in the production of final services as in control over data, computing infrastructure, standards, and intellectual property rights. For this reason, contemporary political-economic discourse increasingly advances the concept of AI sovereignty – the technological sovereignty of states over data, models, and computing resources (Jelinek, 2023; Couture, Toupin, 2019). While earlier research primarily focused on the productivity effects of AI, recent literature increasingly treats AI as a critical infrastructure comparable to energy or financial networks, where control determines states' strategic autonomy. A central element of this infrastructure is the global cloud ecosystem, concentrated in the hands of a limited number of providers (Amazon Web Services, Microsoft Azure, Google Cloud). As research in digital political economy demonstrates, cloud and platform ecosystems increasingly function as infrastructural layers that concentrate control over data, computational resources, and access to digital markets, thereby shifting the balance between value creation and value capture in favour of global providers (Plantin, Lagoze, Edwards, et al., 2016; Kenney, Zysman, 2020). For economies that do not possess their own hyperscale resources, this implies a risk of persistent dependency even in the presence of strong human capital and entrepreneurial dynamism. Innovation activity may remain embedded within external platforms without the emergence of a domestic product core.

Particular importance is also attached to the concept of compute sovereignty, which links technological autonomy to control over GPU capacity, data centres, and semiconductor supply chains. Under contemporary conditions, access to computational resources is increasingly becoming a factor of geopolitical competition, while export restrictions on advanced chips and sanctions regimes are creating a new dimension of global asymmetry in AI development (Hawkins, Lehdonvirta, Wu, 2025; Lehdonvirta, Wú, Hawkins, 2024). Accordingly, computing infrastructure (compute) is no longer a neutral technological resource, but a strategic asset that determines the possibility of transitioning from a service-based model to control over products and markets. In response to these challenges, the European Union is advancing policies of digital strategic autonomy aimed at reducing dependence on external platforms and developing its own computing and data infrastructure, reflecting a broader trend towards the institutionalisation of technological sovereignty in the AI economy (Gaia-X, n.d.; European Parliament & Council of the European Union, 2023).

For Ukraine, this issue is particularly acute in connection with the state's wartime digital resilience. After 2022, a significant share of critical government data and digital services was hosted in cloud infrastructures outside national jurisdiction, ensuring continuity of operations but at the same time increasing dependence on external platforms and legal regimes. The literature emphasises that cross-border data storage may create risks of extraterritorial access, reduced control, and loss of strategic autonomy, which became one of the key drivers of digital sovereignty debates and data localisation policies following the Snowden revelations (Pohle, Thiel, 2020; Tréguer, 2017; Tréguer, 2018; Chander, Le, 2015). Accordingly,

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the development of AI in Ukraine cannot be viewed solely as a matter of innovation policy; it forms part of a broader issue of economic security and the capacity to retain technological rents within the national economy.

Thus, the analytical section demonstrates that Ukraine's digital sector, in particular exports of computer services, performs the function of an important foreign-exchange stabiliser during wartime; however, its long-term contribution to productivity and reconstruction depends on the economy's ability to transition from a service-based model to retaining value added in the form of products, intellectual property, and export-scalable AI solutions. The key economic barriers along this path include high transaction costs associated with scaling AI solutions in the real sector, fragmented access to data, constraints on compute resources, regulatory uncertainty regarding liability, and a low level of standardised trust in AI systems within critical domains. Under such conditions, the technological potential of AI does not automatically translate into macroeconomic impact, but requires an institutionally organised architecture capable of removing barriers to diffusion and commercialisation.

For this reason, the following section focuses on the legal elements through which the state can influence the entire AI value-creation chain – from regimes governing access to data and cloud infrastructure to compliance standards, the allocation of liability, and the export compatibility of products. Each of these elements carries not only normative but also economic significance, as it determines the capacity to scale AI solutions and retain value added within the national economy. The effectiveness of such regulation may be operationalised through specific key performance indicators (KPIs), including increased availability of government datasets for reuse, expansion of national compute capacity, the share of certified high-risk AI systems, a reduction in personal data incidents, and growth in exports of high-technology products rather than services alone. Accordingly, the legal framework for AI development should be viewed as an institutional mechanism of economic security and structural modernisation, rather than as a secondary accompaniment to technological processes.

Legal Framework for AI Development in Ukraine: Elements (Nodes), Data – Models – Products – Export

The legal framework for the development of AI in Ukraine cannot be reduced to declarative support for innovation or isolated digitalisation programmes, since AI is not an autonomous technological domain but a systemic infrastructure of a new economic order, in which the competitiveness of the state is determined by its capacity to construct a full value-creation chain – from access to data and computational resources to models, products, trust standards, liability regimes, and export compatibility. For this reason, an effective national AI policy must be institutionally organised as an integrated system of interrelated elements: "data, computing infrastructure, models, products, standards, liability, and export" where each component constitutes a necessary precondition for the functioning of the next, and deficiencies in legal regulation at any level create systemic barriers to the economic diffusion of technology.

The primary element of this architecture is the regime of access to high-quality datasets, as the economic impact of AI, manifested in productivity gains, value creation, and the development of competitive products, directly depends on the ability to lawfully use non-financial and non-personal data from the real sector, particularly in areas such as energy, transport, logistics, construction, land cadastre, and industry. Ukraine already possesses a regulatory foundation for open data policy and a centralised open data portal, established, inter alia, pursuant to the Resolution of the Cabinet of Ministers of Ukraine "On Approval of the Regulation on Datasets Subject to Publication in the Form of Open Data" of 21 October 2015 No. 835. However, in practice, the availability of "high-value" datasets for training and testing models remains fragmented, non-standardised, and constrained due to diverse access regimes, weak metadata quality, lack of API interoperability, and the absence of standardised data-sharing mechanisms for business and research. The European approach to developing sectoral data spaces, as reflected in the Data Governance Act (European Parliament & Council of the European Union, 2022) and the Data Act (European Parliament & Council of the European Union, 2023a), demonstrates that the key condition for AI development is not merely data openness, but the creation of a trust-based infrastructure for data reuse, where legal constructs such as data trusts reduce transaction costs of access and stimulate the scaling of applied models.

The second element is the personal data economy, where GDPR compatibility is not merely a formal requirement of European integration but a precondition for Ukraine's participation in the Digital Single Market and in international AI value chains. In this context, it is important to avoid the mythologisation of regulatory change. Draft Law No. 8153 "On Personal Data Protection" (Verkhovna Rada of Ukraine, 2022) has only been approved at first reading in 2024, and therefore the principal challenge remains not the declaration of reforms but the establishment of legal certainty regarding lawful bases for personal data processing, the roles of controller and processor, procedures for Data Protection Impact Assessments (DPIA), regimes governing automated decision-making, and cross-border transfers to cloud environments. It is precisely in this area that secondary legislation on pseudonymisation and anonymisation standards for machine learning is required, creating "safe harbor" scenarios for innovative businesses and reducing regulatory uncertainty.

The third element is computing and cloud infrastructure, which acquires particular importance for Ukraine in the wartime context. After 2022, the relocation of data to global cloud environments (AWS, Azure) became a rational mechanism for ensuring the continuity of critical government and business services (according to available estimates, more than 150 state registries and data volumes amounting to several petabytes were migrated to cloud infrastructure, enabling the preservation of digital state functions under conditions of wartime shock (The Wall Street Journal, n.d.)). However, in the long term, this creates risks of external jurisdictional dependence and extraterritorial access. Accordingly, unlike the emergency cloud migration measures described in the literature (Aviv, Ferri, 2023), a long-term strategy should be based on the establishment of a legal regime of managed digital resilience. Such a regime should include: (1) the legal classification of data by criticality level, whereby strategic state registries and infrastructure datasets are hosted only in sovereign or certified environments; (2) the formal recognition of trusted cloud infrastructure for the public sector, with mandatory provider certification, auditing, and transparency of access; and (3) sovereign key management ensuring institutional control over data access regardless of the jurisdiction of hyperscale platforms. The effectiveness of such a policy may be assessed through the share of critical government data hosted in certified environments and the degree of national control over encryption and backup infrastructure. European digital sovereignty initiatives, including GAIA-X (n.d.) and the European Chips Act (European Parliament & Council of the European Union, 2023), demonstrate that computing infrastructure is not merely a technical asset but a geo-economic and security resource of strategic autonomy.

The fourth element, "models and their lifecycle", requires a shift in regulatory focus from declarative calls to "develop AI" towards ensuring the legal integrity of training, testing, validation, and deployment, particularly in high-risk domains. The EU's risk-based approach, enshrined in the AI Act (European Parliament & Council of the European Union, 2024), establishes a standard whereby transparency, documentation, human oversight, and post-market monitoring become not merely ethical recommendations but legal conditions for market participation. For Ukraine, this implies the need to introduce regulatory regimes for model cards, dataset documentation, logging, and audits for critical applications, especially in the fields of reconstruction, social benefits, and critical infrastructure.

The fifth element, "AI products and intellectual property rights", determines the state's capacity for value capture, that is, its ability to retain economic gains not in the form of outsourced services but through scalable products. Legal regulation must clearly define the ownership of model weights, rights to datasets, regimes governing fine-tuning and derivative models, as well as mechanisms for the protection of trade secrets. Without such a framework, Ukraine risks remaining in the peripheral position of a service market rather than becoming a product-based exporter.

The sixth element, "standards and compliance", constitutes the foundation for building trust as an infrastructure of export. Access to EU markets requires not "ethics in presentations," but compatibility with procedural risk-management standards such as ISO/IEC 42001 and NIST AI RMF 1.0, which translate principles of accountability into concrete governance procedures (ISO/IEC, 2023; NIST, 2023).

The seventh element, "liability", defines the boundaries of legal predictability, without which investors and clients tend to avoid the adoption of AI solutions. The European Union is already modernising liability for defective products, explicitly incorporating software and AI systems into the scope of product law (European Parliament & Council of the European Union, 2024a). For Ukraine, this implies the need for a clear allocation of liability among developers, integrators, and operators, as well as mandatory requirements for logging, incident reporting, and pre-trial redress mechanisms in public services.

The final element of this institutional architecture is international integration and the export orientation of AI products. Regulatory compatibility with European and global standards in the field of AI constitutes a necessary condition for integrating Ukrainian developers into international value chains. In other words, for Ukrainian AI solutions to be successfully exported, they must *a priori* comply with the requirements of target markets regarding transparency, safety, privacy, and ethical governance. In this sense, the harmonisation of approaches to risk assessment, data protection, and the allocation of liability directly contributes to reducing barriers to the cross-border flow of technology and creates a trust framework for products developed within the national jurisdiction (OECD, n.d.; Global Partnership on Artificial Intelligence, 2023) (Table 2).

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Table 2. Institutional risks in the field of AI, legal instruments, and performance indicators.

Institutional Risk	Legal Instrument / Approach	Indicative Performance Indicator (KPI)
Lack of data for AI, fragmentation of datasets	Open data legislation; standardised cross-sector data-sharing mechanisms	Share of government data available in open format; number of datasets available for reuse via APIs and standardised metadata
Privacy violations, lack of user trust	Harmonisation with GDPR; technical standards for anonymisation	Number of data subject complaints; number of incidents involving unlawful processing or personal data breaches
Dependence on foreign cloud providers and jurisdictional risks	Classification of critical data; trusted cloud infrastructure regime; sovereign key management	Share of critical government data hosted in certified environments; share of systems with national control over encryption and backup keys
Limited access to computing resources	High-performance computing (HPC) support policy; incentives for data centres as critical infrastructure	Available computing capacity for science and innovation (PFLOPS); number of national AI centres with GPU clusters; number of programmes providing compute access for startups
Shortage of human capital and a weak research base	Tax incentives and grants for AI R&D; special legal regimes (e.g., Diia.City)	Number of AI startups; AI R&D expenditure (% of GDP); Ukraine’s position in international AI indices
Risks from uncontrolled AI systems in high-risk domains	Conformity assessment and certification based on the EU AI Act; algorithmic auditing	Number of pilot AI audits in the public sector (per year); number of AI systems certified after EU AI Act implementation; number of registered incidents or algorithm withdrawals (per year)
Uncertainty in liability allocation for harm	Updated liability legislation; logging and monitoring requirements for AI systems	Number of disputes related to AI decisions; average incident response time; share of pre-trial settlements
Entrenchment of the service (outsourcing) model and loss of value added in Ukraine	Regulatory compatibility with EU requirements; support programmes for AI product exports; protection of intellectual property rights	Share of product exports in the IT sector structure; number of Ukrainian AI products entering EU/US markets

Thus, the effectiveness of the legal framework for the development of AI is determined not by isolated or fragmented measures, but by the coherence of the institutional architecture as a whole. Only a comprehensive approach to addressing the identified gaps will enable the transformation of the existing technological potential of AI into a sustainable economic effect – enhanced productivity, strengthened foreign-exchange stability, and the consolidation of Ukraine’s position as a provider of high-technology solutions rather than a peripheral participant in low-value segments of global value chains.

DISCUSSION

The findings of this study indicate that AI in the Ukrainian context functions primarily as an infrastructural driver of productivity and economic resilience rather than merely a domain of digital innovation. While previous research has established the systemic productivity effects of AI in stable economies (Bughin et al., 2018; Kalai et al., 2024), the present study demonstrates that in conflict-affected and reconstruction settings, the economic impact of AI is mediated more strongly by institutional and legal conditions than by technological adoption alone. This suggests that the relationship between AI and economic growth is context-dependent and shaped by structural constraints, supporting the institutional perspective on technology-driven development.

The empirical results confirm that Ukraine’s digital sector has retained macroeconomic importance during wartime, particularly through its foreign-exchange stabilising function. However, consistent with institutional economic theory (North, 1990; Acemoglu et al., 2005), the findings show that technological activity and IT exports alone do not guarantee sustained productivity gains. The key determinant is the capacity for value capture – the ability of the national economy to retain technological rents, intellectual property, and product-level control. This result aligns with concerns raised in the literature regarding the persistence of service-based dependency in technologically active but structurally constrained economies (Gereffi, 2018; Korinek & Stiglitz, 2021).

At the same time, this study extends prior research by demonstrating that in post-war reconstruction contexts, AI operates not only as a productivity-enhancing technology but also as a coordination infrastructure capable of reducing transaction costs and improving resource allocation in critical recovery processes. This interpretation is consistent with studies on technological augmentation and data-driven governance (Dorn, 2019; Rawat et al., 2024), yet the Ukrainian case reveals a stronger systemic role of AI under conditions of capital scarcity, institutional transformation, and structural disruption.

Furthermore, the findings support recent empirical research emphasising the importance of human capital and infrastructure in shaping national AI ecosystems (Ojeda-Castro et al., 2025). However, this study shows that in transitional and conflict-affected economies, regulatory certainty, trusted digital infrastructure, and structured data governance become central determinants of technological diffusion. This observation complements research on technological sovereignty, which highlights that control over data, computing infrastructure, and digital platforms increasingly defines states' strategic autonomy (Mügge, 2024; Farrell & Newman, 2019; Kenney & Zysman, 2020).

From a policy perspective, the results imply that AI development should be conceptualised not as a sectoral innovation policy but as a component of economic security and structural modernisation. In particular, the study underscores the importance of data governance regimes, trusted cloud infrastructure, compute sovereignty, certification of high-risk AI systems, and legal clarity regarding liability and intellectual property as institutional preconditions for scaling AI and retaining value added domestically. These findings contribute to the emerging literature linking digital governance with economic resilience and technological autonomy.

Nevertheless, several limitations must be acknowledged. First, the empirical analysis relies primarily on macro-level indicators and proxy measures rather than firm-level microdata, limiting the precision of causal inference. Second, the measurement of AI activity through digital sector indicators may underestimate emerging or informal AI adoption. Third, the institutional model proposed in this study is conceptual and requires further empirical validation. Finally, the rapidly evolving regulatory environment, particularly the implementation of the EU AI Act, may reshape the institutional conditions analysed here, requiring longitudinal assessment. Future research should therefore prioritise firm-level microdata, indicators of AI intensity, patent dynamics, and R&D investment, as well as empirical evaluation of how regulatory harmonisation with European AI governance frameworks influences technological scaling, export capacity, and economic resilience in post-war Ukraine.

CONCLUSIONS

The conducted study allows the conclusion that, in the contemporary economy, AI should be conceptualised not as an autonomous sector of digital innovation, but as a foundational infrastructural technology shaping long-term competitiveness, productivity, and the macroeconomic resilience of the state. For Ukraine, which operates under conditions of full-scale war while simultaneously entering a phase of post-war reconstruction, the development of AI acquires systemic importance, as it determines not only the trajectory of technological modernisation but also the economy's capacity to ensure structural autonomy and to transition from service specialisation to a product-oriented development model based on the commercialisation of AI solutions and the retention of value added within the country. In financial – economic terms, this transition affects the structure of export revenues, the accumulation of intangible assets, and the economy's ability to generate scalable product-based income rather than contract-based service earnings.

The empirical analysis of computer services exports in 2021–2025 demonstrates that Ukraine's digital sector has maintained relative resilience even under conditions of wartime shock, remaining one of the key channels of foreign-exchange earnings. This indicates that technology-intensive sectors, unlike materially and logistically dependent industries, are capable of performing a compensatory function during periods of deep structural disruption and of supporting the state's economic adaptability. Such resilience has direct financial significance, as stable foreign-exchange inflows contribute to external balance sustainability and to maintaining investment capacity during reconstruction.

At the same time, it is argued that the long-term economic impact of AI does not arise automatically from digital activity or IT services exports. A key challenge for Ukraine remains the risk of becoming locked into a "service trap," where integration into global value chains occurs predominantly through contract-based models with limited control over intellectual property, standards, and product commercialisation. Accordingly, the central issue becomes the capacity of the national economy to achieve value capture by retaining value added in the form of products, models, and intellectual property rights, thereby securing income within the jurisdiction and strengthening the domestic revenue base linked to high-value-added digital production.

It is substantiated that the barriers to scaling AI in Ukraine are primarily institutional and economic in nature, manifesting in high transaction costs of technology diffusion in the real sector, fragmented access to data, shortages of computing infrastructure, insufficient levels of standardised trust in AI solutions within critical domains, and uncertainty regarding the allocation of liability. Under such conditions, the technological potential of AI does not translate into productivity gains without a purposeful institutional architecture capable of removing the structural constraints on development. These constraints also limit investment incentives and increase the cost of capital for AI-based projects.

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The scientific contribution of the article lies in the development of a seven-element model of the legal framework for AI ("data – computing infrastructure – models – products – standards – liability – export"), which operationalises AI development as a complete value-creation chain within a conceptual and institutional approach. It is demonstrated that legal regimes governing access to data, trusted cloud infrastructure, certification of high-risk systems, protection of intellectual property rights, and liability are the key institutional conditions enabling the commercialisation and international scalability of Ukrainian AI products.

Of particular importance for Ukraine is the element of compute sovereignty and managed digital resilience. The relocation of critical services to global cloud environments after 2022 became a rational mechanism for ensuring continuity; however, in the long term, it generates risks of external jurisdictional dependence and loss of strategic autonomy. Accordingly, an effective model cannot be reduced to simple data localisation, but requires a legal regime for the classification of critical datasets, certification of trusted providers, and national control over the cryptographic infrastructure of access.

In summary, for Ukraine, AI represents not a situational technological trend, but an instrument of structural economic transformation aimed at increasing productivity, strengthening macroeconomic resilience, and establishing a product-oriented development model. In practical terms, this means that public policy in the field of AI should focus on reducing institutional barriers to the diffusion of technology – developing regimes for data access, establishing trusted cloud infrastructure for critical datasets, introducing certification procedures for high-risk AI systems, and ensuring legal certainty with regard to liability and intellectual property rights. Further research should focus on the use of firm-level microdata, indicators of AI intensity, patent activity, and R&D expenditures, as well as on the empirical assessment of the impact of harmonisation with the EU AI Act on the export potential of Ukrainian AI products in the post-war period.

ADDITIONAL INFORMATION

AUTHOR CONTRIBUTIONS

All authors have contributed equally.

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The Authors declare that there is no conflict of interest.

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АРХІТЕКТУРА ЕКОНОМІЧНОЇ СТІЙКОСТІ УКРАЇНИ В УМОВАХ ВІЙНИ ТА ВІДБУДОВИ: ІНСТИТУЦІЙНІ УМОВИ МАСШТАБУВАННЯ ШТУЧНОГО ІНТЕЛЕКТУ

У дослідженні вивчено штучний інтелект (ШІ) як інфраструктурний драйвер економічної стійкості й продуктивності України в умовах повномасштабної війни та післявоєнної відбудови. Проаналізовано інституційні й економічні умови, що забезпечують дифузію ШІ в реальному секторі, його комерціалізацію у формі продуктових рішень та інтеграцію в експортно орієнтовані ланцюги створення доданої вартості. Дослідження ґрунтується на положенні про те, що ШІ слід розглядати не як окремий цифровий сектор, а як базову (фундаментальну) технологію, що формує тривалу конкурентоспроможність, продуктивність і здатність економіки утримувати створену додану вартість. На основі актуальних даних щодо експорту комп'ютерних послуг України в статті показано, що технологічно інтенсивні види діяльності зберегли відносну стійкість під час воєнного шоку та продовжують виступати вагомим джерелом валютних надходжень. Це підкреслює макроекономічну значущість цифрового сектора через його внесок у стабільність зовнішнього балансу та збереження інвестиційної спроможності в умовах структурних порушень. Водночас тривалий економічний ефект від розвитку ШІ не виникає автоматично на основі експорту IT-послуг. Ключовим викликом є ризик збереження моделі контрактного сервісного аутсорсингу з обмеженим контролем над інтелектуальною власністю та комерціалізацією продуктів. У цьому контексті вирішального значення набуває спроможність до захоплення (утримання) вартості: збереження доходів від продуктів на основі ШІ, об'єктів інтелектуальної власності й масштабованих технологічних рішень як джерела сталого формування доходів і внутрішніх інвестиційних ресурсів. У статті запропоновано семиелементну інституційну модель розвитку ШІ («дані – обчислювальна інфраструктура – моделі – продукти – стандарти – відповідальність – експорт»), що відображає повний ланцюг створення вартості. Отримані результати свідчать, що узгоджене регулювання доступу до даних, обчислювальних потужностей, стандартів довіри та правил відповідальності є необхідною умовою комерційного впровадження рішень на основі ШІ, зміцнення економічної стійкості й переходу до стабільних експортних надходжень і продуктово орієнтованих потоків доходів протягом періоду відбудови.

Ключові слова: штучний інтелект, економічна стійкість, економічна безпека, післявоєнна реконструкція, продуктивність (TFP), експорт комп'ютерних послуг, продуктова (value capture) модель, правове забезпечення ШІ, обчислювальний суверенітет (compute sovereignty), EU AI Act

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