УДК: 339.9+330.34:004.8+330.5:004.8
DOI:

DIGITAL AGENTS AS FUNCTIONAL EQUIVALENTS OF ECONOMIC ACTORS: THE DECOUPLING OF DEMOGRAPHICS AND ECONOMIC GROWTH

ЦИФРОВІ АГЕНТИ ЯК ФУНКЦІОНАЛЬНИЙ ЕКВІВАЛЕНТ ЕКОНОМІЧНОГО СУБ'ЄКТА: РОЗРИВ ЗВ'ЯЗКУ МІЖ ДЕМОГРАФІЄЮ ТА ЕКОНОМІЧНИМ ЗРОСТАННЯМ

Nataliia Reznikova
Doctor of Sciences (Econ.), Professor, Professor of the Department of World economy and International Economic Relations, Educational and Scientific Institute of International Relations, Taras Shevchenko National University of Kyiv, Ukraine,
e-mail: nreznikova@knu.ua
ORCID ID: https://orcid.org/0000-0003-2570-869X
Volodymyr Panchenko
Doctor of Economic Sciences, Associate Professor, Professor of the Department of Economics and International Economic Relations, Mariupol State University, Kyiv, Ukraine,
e-mail: panchenkopvg@gmail.com
ORCID ID: https://orcid.org/0000-0002-5578-6210
Mykhailo Grod
PhD in international economic relations, Associate Professor, Department of Management, Marketing and Public Administration, National Academy of Statistics, Accounting and Audit, Ukraine,
e-mail: grodmihail@ukr.net
ORCID ID: https://orcid.org/0000-0002-7539-5778

Наталія Резнікова
Доктор економічних наук, професор, професор кафедри світового господарства і міжнародних економічних відносин Навчально-наукового інституту міжнародних відносин Київського національного університету імені Тараса Шевченка,
e-mail: nreznikova@knu.ua
ORCID ID: https://orcid.org/0000-0003-2570-869X
Володимир Панченко
Доктор економічних наук, доцент, професор кафедри економіки та міжнародних економічних відносин, Маріупольського державного університету, Київ, Україна,
e-mail: panchenkopvg@gmail.com
ORCID ID: https://orcid.org/0000-0002-5578-6210
Михайло Грод
Доктор філософії зі спеціальності «Міжнародні економічні відносини», доцент кафедри менеджменту, маркетингу та публічного управління Національної академії статистики, обліку та аудиту, Київ, Україна,
e-mail: grodmihail@ukr.net
ORCID ID: https://orcid.org/0000-0002-7539-5778

Abstract. *The purpose of the article is to substantiate the theoretical interpretation of digital agents as functional equivalents of economic actors and to demonstrate that their expanding role in production and market processes creates the preconditions for a gradual decoupling of demographic dynamics from economic growth, thereby transforming the foundations of production, labour markets, institutional arrangements and the international distribution of economic power. The article proposes a theoretical interpretation of AI-based digital agents as functional equivalents of economic actors, creating preconditions for decoupling the centuries-old link between demographic dynamics and economic growth. The concept of shadow demographics is substantiated as an analytical category describing a growing algorithmic population that expands in parallel with the stagnation or decline of the human population, while the prospect of its transformation into algorithmic demographics through the institutionalisation of digital agent registration is outlined. The transformation of the ontological status of technology is analysed - from a productivity-enhancing tool to an autonomous participant in economic processes, forming a hybrid factor of production that combines characteristics of both capital and labour. An approach to the quantitative identification of* *algorithmic agents through the category of cognitive full-time equivalent (cFTE) is proposed, enabling the comparison of algorithmic and human productivity within a unified analytical framework, alongside the category of agent energy profile (AEP) as a measure of annual energy consumption per unit of cFTE. The fundamental asymmetry between economic and social reproduction is examined, arising from the capacity of digital agents to compensate for the productive functions of the population while being unable to substitute its functions of social reproduction. It is demonstrated that the institutional architecture of modern societies - from pension systems to taxation models - is built upon assumptions systematically undermined by the agentic economy, necessitating a revision of fiscal and social models, particularly through the introduction of discrete taxation of algorithmic employment. The geoeconomic dimension of algorithmic transformation is analysed, whereby the capacity to create, maintain, and control digital agents becomes a new axis of international inequality, potentially devaluing the demographic dividend of developing countries and creating preconditions for revising the logic of comparative advantages. Particular attention is given to algorithmic collusion as a new form of market failure.*

Keywords: *shadow demography, algorithmic demography, algorithmic population, digital agents, cognitive full-time equivalent, agent capital, human capital, agent energy profile, artificial intelligence, labour market, growth, institutional inertia, geoeconomics, inequality, shadow economy, IT market, digital market.*

Анотація. *У статті пропонується теоретична інтерпретація цифрових агентів на основі штучного інтелекту як функціональних еквівалентів економічних суб'єктів, що створюють передумови для розриву багатовікового зв'язку між демографічною динамікою та економічним зростанням. Обґрунтовується концепція тіньової демографії як аналітичної категорії для опису зростаючої алгоритмічної популяції, що розширюється паралельно зі стагнацією або скороченням людського населення, та показано перспективу її трансформації у алгоритмічну демографію (algorithmic demographics) внаслідок інституціоналізації обліку цифрових агентів. Аналізується трансформація онтологічного статусу технології - від інструменту підвищення продуктивності до автономного учасника економічних процесів, що формує гібридний фактор виробництва, який поєднує характеристики капіталу та праці. Запропоновано підхід до кількісної ідентифікації алгоритмічних агентів через категорію когнітивного еквіваленту повної зайнятості (cFTE), що дозволяє співвіднести алгоритмічну та людську продуктивність у межах єдиного аналітичного простору, а також категорію енергетичного профілю агента (AEP) як характеристику питомого річного обсягу споживання енергії на одиницю cFTE. Досліджується фундаментальна асиметрія між економічним та соціальним відтворенням, що виникає внаслідок здатності цифрових агентів компенсувати виробничі функції населення за неможливості заміщення його функцій соціального відтворення. Показано, що інституційна архітектура сучасних суспільств - від пенсійних систем до моделей оподаткування - побудована на припущеннях, які систематично підриваються агентною економікою, що зумовлює необхідність перегляду фіскальних і соціальних моделей, зокрема через запровадження дискретного оподаткування алгоритмічної зайнятості. Аналізується геоекономічний вимір алгоритмічної трансформації, у межах якого здатність створювати, утримувати та контролювати цифрових агентів стає новою віссю міжнародної нерівності, що потенційно знецінює демографічний дивіденд країн, що розвиваються, та формує передумови для перегляду логіки порівняльних переваг. Окрему увагу приділено проблемі алгоритмічної колюзії як нової форми ринкових провалів.*

Ключові слова: *тіньова демографія, алгоритмічна демографія, алгоритмічна популяція, цифрові агенти, когнітивний еквівалент повної зайнятості, агентний капітал, людський капітал, енергетичний профіль агента, штучний інтелект, ринок праці, зростання, інституційна інерція, геоекономіка, нерівність, тіньова економіка, IT ринок, цифровий ринок.*

Introduction. For millennia, the relationship between population and economic growth has been regarded as axiomatic. From agrarian societies to industrial economies, demographic dynamics have determined the volume of production, the depth of markets and the stability of fiscal systems.

Classical models of economic growth, from Malthusian to neoclassical, have treated labour as a key factor of production, while its quantity has been interpreted as a function of demographic dynamics *(Kremer, 1993; Acemoglu & Restrepo, 2018).* Strategic development forecasts have been based on the following: demographic ageing in China and the European Union has been interpreted as a factor in growth deceleration, whereas the young populations of India and African countries have been viewed as a foundation for global economic leadership in the twenty-first century. According to recent global labour and demographic projections, the reconfiguration of the global workforce and the shifting balance of human capital across regions are expected to transform the geography of economic growth and technological leadership in the coming decades *(World Economic Forum, 2025),* India's population has already exceeded that of China, and the population of the African continent is expected to double by 2050, which within classical logic would imply a shift in the global centre of economic gravity. However, in the second decade of the twenty-first century, this logic has begun to undergo a potentially fundamental revision. Contemporary economies increasingly compensate for demographic slowdown not through higher fertility or migration, but through the creation of artificial participants in economic processes - digital agents. Algorithms generate content, process information, execute transactions, optimize logistics and support managerial decision-making. They are not reflected in demographic statistics, yet directly influence productivity and the structure of labour markets. Artificial intelligence thus transforms markets not merely as a tool but as a full-fledged participant in economic relations capable of concluding transactions, making decisions, and learning in digital environments *(Shahidi et al., 2025).*

If demographic decline necessarily implied economic decline, the logic of projections for China and the European Union would remain consistent. However, if digital agents can functionally compensate for the reduction in human labour in production processes, this relationship ceases to be linear, and the predictive value of purely demographic models declines significantly. Similarly, the demographic dividend of countries with young populations may prove less decisive than previously assumed if cognitive labour becomes algorithmically reproducible.

The study's relevance is determined by several interrelated factors. First, the scale of implementation of algorithmic agents has already crossed the threshold of statistical significance: artificial intelligence-based agents and robotic systems can generate substantial economic value annually in advanced economies *(McKinsey Global Institute, 2025).* Second, empirical studies record the actual substitution of human labour by algorithmic agents in a number of sectors, transforming a theoretical discussion into a practical economic challenge (*Brynjolfsson, Chandar & Chen, 2025; Ozkan & Sullivan, 2025).* Third, the existing categorical apparatus of economic science - particularly the concepts of population, labour market, and factors of production - proves insufficient for an adequate description of the emerging reality, which necessitates further conceptual and theoretical development.

The purpose of the article is to conceptualize digital agents as functional equivalents of an economic entity and to analyse the structural consequences of this transformation for the relationship between demography and growth, the institutional architecture of societies, and the international distribution of economic power. Achieving this goal involves solving the following tasks: substantiating the change in the ontological status of technology from a tool to an autonomous participant in the economic process; conceptualizing shadow demography as an analytical category and substantiating the prospect of its transformation into algorithmic demography; developing an approach to the quantitative identification of algorithmic agents through the categories of cFTE and AEP; analysing the fundamental asymmetry between economic and social reproduction; studying the institutional and fiscal consequences of the agent economy; analysing the geoeconomic dimension of algorithmic transformation. The article's methodological basis is a theoretical and analytical approach aimed at conceptualizing the transformation of production factors under the influence of algorithmic technologies. The study is based on a structural-functional analysis that reveals the functional equivalence of digital agents and human participants in the economic process, without identifying their ontological status. The comparative-historical method is used to compare the current technological transformation with previous technological revolutions. The use of a case-oriented approach is heuristic and serves to demonstrate the practical consequences of theoretical provisions.

Literature review. Modern research on the transformation of labour, productivity, and the competence structure of the economy in the context of robotization and digitalization emphasizes the growing role of human capital as a key intangible resource for economic development and competitiveness *(Rubtsova & Reznikova, 2018a; Rubtsova & Reznikova, 2018b).* Within the framework of the analysis of global structural changes, attention is focused on the formation of a "new normal" of the world economy, which is accompanied by increased systemic risks, changes in consumption and ownership patterns, and the transformation of the logic of economic behaviour in the context of the transition to stakeholder capitalism and increased geoeconomic turbulence *(Panchenko, V. H. et al., 2024; Reznikova & Ivashchenko, 2017; Reznikova et al., 2023; Reznikova & Panchenko, 2023).* A separate area of research is shaping the idea of data and information technology markets as a space of strategic competition for digital leadership, where technological competencies and access to intellectual resources become determining factors in the positioning of countries and companies in the global economy *(Reznikova et al., 2025; Reznikova et al., 2023).* Within the framework of international business and the digital economy, attention is increasing to the role of human capital as a fundamental intangible asset, to the processes of socialization of public and corporate governance, as well as to the transformation of global markets under the influence of digital trade and the media economy *(Vergun, 2020; Pryiatelchuk, 2017; Pryiatelchuk & Naida, 2025; Pryiatelchuk, 2023; Pryiatelchuk & Bekh, 2020).* The combination of these approaches provides a theoretical basis for analysing digital transformations of the international economy, in which technological changes, human capital, and new forms of economic interaction are considered interrelated factors in the structural restructuring of the global system.

The impact of artificial intelligence on economic growth and the labour market has become the focus of intensive research, which can be systematised along several analytical directions. The first group of studies examines the macroeconomic consequences of automation within the framework of neoclassical and post-neoclassical growth models. Within this approach, the dynamics of the «race between man and machine» are analysed through the interaction between technological change and labour displacement, demonstrating that technological progress simultaneously replaces workers in routine tasks and generates new, specifically human forms of economic activity *(Acemoglu & Restrepo, 2018).* Further development of this analytical perspective emphasises that the macroeconomic effects of artificial intelligence depend on whether it primarily automates existing tasks or creates new productive opportunities, thereby shaping the trajectory of productivity, employment and income distribution (*Acemoglu, 2024).* In this context, artificial intelligence is understood not merely as an additional technology but as a distinct form of capital capable of partially or fully substituting for human labour across an expanding range of functions.

In traditional growth models, productivity increases through the accumulation of physical and human capital. Within the emerging macroeconomics of artificial intelligence, a third component is introduced: algorithmic or cognitive capital, characterized by high scalability and rapid diffusion across sectors and regions. This shift places the elasticity of substitution between human labour and digital agents at the centre of macroeconomic analysis. When artificial intelligence complements labour, it enhances productivity and income growth. When it operates as a functional substitute, a divergence may arise between productivity dynamics and the trajectories of employment and wages. Under such conditions, the prospect of economic growth without a proportional increase in labour input becomes increasingly plausible. The analytical consequence of this transformation is a gradual decoupling of economic growth from demographic dynamics, as productive capacity can expand even amid population stagnation or decline, given the scalable nature of algorithmic agents and their ability to perform cognitive, managerial, and innovative functions. Trammell and Korinek demonstrate that full automation of production, in which machines can self-reproduce, can dramatically accelerate economic growth while reducing the share of labour in income, thereby challenging the Kaldor facts that long characterized growth at the technological frontier *(Trammell & Korinek, 2023).*

A second group of studies focuses on the empirical labour market effects of artificial intelligence adoption. Large-scale analyses of wage and employment data reveal significant employment declines among younger workers in occupations with high exposure to artificial intelligence, indicating structural shifts in labour demand (*Brynjolfsson, Chandar & Chen, 2025).* Complementary research identifies a correlation between the diffusion of generative artificial intelligence and rising unemployment within exposed occupational groups, suggesting that technological substitution effects are already observable in contemporary labour markets *(Ozkan & Sullivan, 2025).* Further assessments of large language models highlight their character as general-purpose technologies capable of affecting a wide spectrum of professional activities and task structures across sectors *(Eloundou et al., 2024).*

A third research direction explores the transformative potential of artificial intelligence agents as a new type of economic actor. Analytical work on the emerging «agentic economy» demonstrates that AI agents can reshape demand, supply, and market design by altering traditional market coordination mechanisms and reducing transaction costs associated with human attention and decision-making *(Shahidi et al., 2025).* Conceptual studies of agent-based artificial intelligence further emphasise the transformation of capitalism through the emergence of agentic capital and new forms of value creation rooted in algorithmic autonomy *(Klover.ai, 2025).* The broader implications of transformative artificial intelligence for development strategies, income distribution, and global economic dynamics are examined through the lens of international political economy and technological change *(Korinek, 2024; Korinek & Stiglitz, 2021).* A fourth strand of research focuses on algorithmic behaviour in markets, particularly the phenomenon of algorithmic collusion. Studies of reinforcement learning systems demonstrate that pricing algorithms can «learn» collusive strategies without explicit programming, revealing the potential for autonomous coordination among digital agents *(Calvano et al., 2020).* Empirical analyses based on real market data further confirm these findings, showing that algorithmic pricing can contribute to coordinated market outcomes in competitive environments *(Assad et al., 2024).*

At the same time, several significant gaps remain in existing literature. First, there is no comprehensive conceptualisation of an algorithmic population as a demographic phenomenon, as most studies focus on sector-specific effects of automation rather than on systemic shifts in the relationship between human population and algorithmic agents. Second, an analytical framework for quantitatively comparing algorithmic and human productivity within a unified measurement system has not yet been developed. Third, the institutional implications of algorithmizing, particularly for pension systems, taxation models, and the broader mechanisms of social reproduction, are examined only fragmentarily and without integration into a coherent theoretical framework. Fourth, the geoeconomic dimension of algorithmic transformation remains insufficiently explored, especially the question of how unequal capacities to create and control digital agents may generate new axes of international inequality and reshape the distribution of economic power in the global economy.

Main results of the research. Traditional economic theory treats technology as a means of increasing the productivity of human labour. In classical models, including the Cobb-Douglas production function, technological progress is included as a parameter that multiplies the efficiency of production factors but does not create a new factor. Even in the most ambitious models of automation of the twentieth century - from Ford's assembly line to industrial robots - machines remained tools that supplemented or replaced human physical labour in narrowly defined operations. Their economic effect was to increase each worker's productivity and, accordingly, to raise per capita productivity indicators. In this paradigm, technology has always been mediated by humans: a CNC machine tool (computer numerical control), an assembly line, or an industrial robot required a human operator, programmer, or adjuster.

The new generation of digital agents is qualitatively changing this picture. As demonstrated in studies on the transformation of capitalism under the influence of agent-based artificial intelligence, modern agents are not simply tools used by humans but systems capable of performing work autonomously *(Klover.ai, 2025).* Their defining characteristics - autonomy, purposefulness, and adaptive learning - provide them with the capacity to make independent economic decisions, from production and exchange to negotiation and investment. This introduces a non-human actor into the core of capitalist processes and challenges the basic assumptions of an economic system historically grounded in human behaviour, incentives, and constraints. The result is a hybrid factor of production that researchers increasingly conceptualise as agentic capital or digital labour. Classical economics traditionally defines factors of production as land, labour, and capital, with labour implicitly referring to human labour in both its physical and cognitive forms. Artificial agents, as privately owned software systems, formally belong to capital. However, this represents a unique form of capital, since it autonomously performs the cognitive component of labour. This reclassification has implications that extend beyond terminology, fundamentally affecting the interpretation of markets, income distribution and the nature of economic activity itself *(Korinek, 2024; Korinek & Stiglitz, 2021).*

The scale of the potential consequences is determined by the fact that the current transformation concerns not merely the automation of individual operations but the possibility of a systemic replacement of cognitive labour. Full automation of production, including the automation of research and development, is expected to significantly accelerate economic growth and alter the distribution of income between capital and labour *(Trammell & Korinek, 2023).* Estimates of the economic value generated by artificial intelligence further underscore the magnitude of this transformation, indicating that AI-based agents and robotic systems can produce substantial annual economic value in advanced economies *(McKinsey Global Institute, 2025).*

In parallel, the rapid development of humanoid robotics is intensifying, with leading technology companies planning to mass-produce humanoid robots by 2030 at projected costs comparable to or lower than the lifetime investment required for the education, healthcare, and social reproduction of a highly skilled worker. The convergence of digital cognitive agents and physical robotic systems suggests that within the next decade, a new type of economic unit may emerge: an autonomous production entity capable of performing both cognitive and physical functions previously dependent on human participation. According to the logic of recursive production, such entities may also acquire the capacity to reproduce technologically similar units, creating the preconditions for the multiplicative expansion of an algorithmic population. This prospective dynamic has no historical precedent in earlier technological transformations and fundamentally distinguishes the contemporary digital revolution from the industrial revolution *(Korinek, 2024; Korinek & Stiglitz, 2021).*

We use the term *«shadow demography»* by analogy with the concept of *«shadow economy»,* introduced into economic science to denote economic activity that is not recorded in official statistics, but has a real impact on macroeconomic processes. Just as the shadow economy has necessitated a review of methods for measuring GDP and employment, shadow demography calls into question the adequacy of existing demographic indicators as indicators of economic potential. *«Shadow demography»* describes the current state of the algorithmic population - a growing number of digital agents that perform economic functions, but are not recorded by any statistical or regulatory accounting system, are not taxed as units of employment and remain invisible to social protection institutions. This is a state analogous to the shadow economy before the introduction of appropriate assessment and regulatory methods. At the same time, the shadow nature of algorithmic demography is not inherent to it - it is a consequence of the lack of institutional mechanisms for accounting and regulation. As identification systems *(similar to the DEAI system proposed below),* mechanisms for taxing algorithmic employment, and standards for measuring the productivity of digital agents are introduced, shadow demography is naturally transformed into algorithmic demographics - a full-fledged object of statistical accounting, regulatory policy, and international comparison. This two-stage logic reproduces the trajectory that the shadow economy took in the 20th century: from ignoring and ad hoc estimates to systematic accounting and integration into macroeconomic statistics. The difference is that algorithmic demography can be integrated into statistical systems much more quickly because the agents themselves are digital, by definition leaving a computational footprint.

The scale of the process is already being quantified. Forecasts indicate that within the next few years, a growing share of operational and strategic work decisions will be delegated to autonomous agent-based artificial intelligence systems, while an increasing number of companies integrating generative artificial intelligence are expected to implement pilot projects involving autonomous agents and expand their use in core business processes. Market assessments further demonstrate the rapid expansion of the artificial intelligence agent sector, which is projected to grow at exceptionally high compound annual growth rates over the current decade.

These dynamics point to an exponential expansion of the algorithmic population, increasingly comparable in scale to demographic processes. If transformative artificial intelligence renders human-level intelligence technologically reproducible, it may fundamentally alter the historical relationship between population and economic growth and signal the transition to a new stage of economic development in which both traditional capital and intelligent machines become reproducible resources and the boundary between them progressively erodes *(Korinek, 2024).* Any attempt to include algorithmic agents in demographic or economic analysis requires solving the problem of their measurement. This problem has both technical and conceptual components. The technical component is that algorithmic agents do not have a stable «corporeal» form: a single software product can perform functions equivalent to the work of dozens of people, or thousands of microagents can coordinate to perform a single task. The conceptual component is the lack of a generally accepted unit of measurement that would allow comparing algorithmic and human performance. Historical experience suggests a productive analogy. Engine power is still measured in horsepower - a unit introduced by James Watt in the late 18th century to compare the performance of steam engines with the tractive power of horses. Although the automobile replaced the horse more than a century ago, this metric remains in common use precisely because it provides intuitive comparability. *By similar logic, it seems appropriate to use a unit that is tied to human productivity to measure the «power» of digital agents.*

The proposed metrological transfer - measuring algorithmic agents in units of human productivity - has a direct historical precedent in the inverse transfer that occurred during the nineteenth century, when units originally developed for machines were systematically applied to the human body. The calorie, coined by the French engineer Nicolas Clément in the early 1820s for calculating the fuel efficiency of steam engines, was transferred to human physiology by German scientists Carl von Voit and Max Rubner in the 1860s-1890s, who used bomb calorimeters - devices that measured the energy content of food by *burning* it in a pressurised chamber - to quantify human metabolism in the same thermodynamic units as mechanical combustion *(Hargrove, 2006)*. This approach was extended to the USA by W. Atwater, whose caloric values (4 kcal/g for protein and carbohydrates, 9 kcal/g for fat) remain standard to this day. The broader intellectual project of treating the working body as a «human motor» - measuring labour in energy units, fatigue in thermodynamic terms, and nutritional needs as fuel requirements - has been extensively documented *(Rabinbach, 1990)*. The same logic of cross-domain commensurability underpinned the concept of «human capital» (Becker, 1964), rendering investment in education analytically equivalent to investment in machinery. In each case, the transfer of metrics across ontological boundaries served not as a claim of identity between entities but as a pragmatic instrument for quantitative comparability. The cFTE and AEP categories proposed in the present article perform the *symmetrical inverse* of this operation: whereas the nineteenth century *«dressed the human in the clothes of the machine»,* measuring bodies as engines and labour as combustion, the twenty-first century *«dresses the algorithm in the clothes of the human»,* measuring digital agents in full-time employment equivalents and their resource requirements in energy-per-unit-of-cognitive-productivity profiles. The calorie precedent also provides a useful caution: the mechanistic model of the body as a combustion engine proved analytically productive for approximately a century before encountering systematic challenges from metabolic science, suggesting that cFTE will function as a workable first approximation whose limits will become apparent as the specificity of algorithmic cognition is better understood.

We propose the cognitive full-time equivalent (cFTE) as the basic unit of measurement for an algorithmic agent's productivity. One cFTE corresponds to the cognitive work performed by one skilled worker in a standard work year (approximately 2,000 hours) in a specific professional context. Under this approach:

• a generative AI system that processes client requests with the speed and quality equivalent to the work of 50 operators would be evaluated as 50 cFTE;

• an algorithmic trader that performs the amount of analysis equivalent to the work of 200 analysts would be evaluated as 200 cFTE;

• an automated programming system that generates code with the speed and quality of 30 developers would be evaluated as 30 cFTE.

The cFTE approach is not perfect, since the cognitive work of a person and an algorithm is qualitatively different. However, it allows us to build an analytical bridge between algorithmic and human productivity, similar to how "horsepower" bridged mechanical and animal traction. Fundamentally, cFTE is a measure of productivity, not subjectivity: it does not imply attributing human qualities to an algorithm, but only allows us to quantitatively compare economic results. To contextualize the scale, it is worth citing a historical analogy. The mid-20th century was characterized by tens of thousands of workers occupying vast office spaces, performing calculations that today can be done by a single laptop. The term «computer» originally meant a person's profession, not a device.

In agriculture, the transformation was even more massive: areas that used to employ thousands of people are now served by a few dozen workers and units of equipment. If these transformations have occurred over decades in physical labour, there is reason to expect a similar transformation in cognitive labour - but in a much shorter time frame. To move from shadow to algorithmic demography, it is necessary to address the problem of identifying and recording digital agents. Today, algorithmic agents are not subject to any form of accounting comparable to that required for legal entities or individuals. They are deployed, scaled, and liquidated without any formal procedure, which makes their «population» largely unobservable for regulatory and statistical authorities.

The analogy with corporate law is instructive. Just as the institution of the legal entity emerged to provide legal status to organisations performing economic functions without being individuals, and just as registers of enterprises record the number, activity, and liquidation of firms, a system of digital economic agent identification *(DEAI)* may be required. Such a system would include registering algorithmic agents that exceed a defined productivity threshold, assigning unique identifiers analogous to corporate identification codes, periodic reporting on productivity and energy consumption indicators, and recording the creation and termination of agents to track the dynamics of the algorithmic population. This approach does not imply the granting of legal personality to algorithmic agents. Rather, it involves statistical and regulatory accounting comparable to vehicle or industrial equipment registration, but focused on economic functionality. The introduction of a DEAI framework would therefore mark the transition from shadow demography to algorithmic demography by transforming an unobserved population into an object of systematic measurement and governance. Recent research already explores regulatory approaches to the governance of digital agents, including proposals for licensing mechanisms and institutional oversight prior to their deployment in sensitive sectors such as finance, law or critical infrastructure management, which supports the feasibility of a structured identification and monitoring system for algorithmic agents *(Shahidi et al., 2025; Bengio et al., 2024).*

The process of algorithmic substitution is already producing measurable empirical effects. Evidence indicates a significant decline in employment among young workers in occupations with high exposure to artificial intelligence, particularly in software development and customer support, where algorithmic systems increasingly perform cognitive and routine tasks *(Brynjolfsson, Chandar & Chen, 2025).* Additional labour market data confirm a reduction in employment shares within occupations most exposed to artificial intelligence following the large-scale deployment of generative AI systems, reflecting early substitution dynamics in knowledge-intensive sectors. Empirical analyses further demonstrate a correlation between the adoption of generative artificial intelligence across occupational groups and rising unemployment within those segments, with computer and mathematical professions experiencing some of the most pronounced effects due to their high level of exposure to algorithmic substitution *(Ozkan & Sullivan, 2025).*

At the same time, aggregate employment continues to expand, indicating that current dynamics reflect substitution rather than absolute displacement of labour. Historical and forward-looking assessments of technological change show that productivity growth driven by advanced technologies may temporarily increase unemployment rates, but this effect tends to dissipate as new forms of employment emerge and labour markets adjust to structural transformation. Long-term employment trends confirm that a substantial share of current occupations did not exist in earlier technological eras, demonstrating the capacity of innovation to generate new forms of work even as existing functions are automated *(Goldman Sachs Research, 2025).*

These findings support two analytically significant conclusions. First, substitution effects are sectorally uneven and possess a distinct cognitive profile, as algorithmic systems primarily replace formalised, repetitive, and codifiable cognitive functions. Second, substitution in the cognitive full-time equivalent dimension occurs at a significantly faster pace than changes in recorded employment, since a single algorithmic agent may perform tasks equivalent to the productivity of multiple human workers, thereby accelerating the expansion of the algorithmic component of the productive system.

The growth of the algorithmic population creates a fundamental asymmetry that has important theoretical and practical implications. Digital agents are capable of performing productive and managerial functions, but they are incapable of performing functions of social reproduction. They do not form political communities, do not create generations, and have no needs for housing, education, or social infrastructure. They compensate for the economic role of the population, but cannot replace it as the basis of society. The analytical depth of this asymmetry is revealed in research demonstrating that artificial intelligence has the potential to disrupt three key functions of work in the modern economy: work as the main scarce factor of production, work as the principal source of income for the majority of the population, and work as the dominant form of time allocation for working-age individuals *(Korinek & Stiglitz, 2021).* Critically, none of these functions can be reduced to pure productivity. They are intertwined with social order, identity, dignity, political participation, and the reproduction of institutions. As a result, the trajectories of economic development and social structure begin to diverge. Economic activity may continue to expand even amid demographic decline, while social institutions remain dependent on human reproduction. Pension systems, educational models, urban infrastructure and mechanisms of political representation were designed for societies characterised by demographic growth or at least stability. They now operate in an environment in which economic activity can be sustained without demographic expansion, creating a structural contradiction between the logic of production and the logic of social reproduction.

This asymmetry acquires an additional dimension in research demonstrating that artificial agents are also transforming the logic of value creation and competition on digital platforms. Contemporary digital platforms traditionally monetise human attention through the optimisation of clicks, engagement and emotional responses; however, the growing presence of autonomous agents capable of interacting with platforms independently of human users alters the structure of demand, supply and market design within digital environments *(Shahidi et al., 2025).* But AI agents don't click or scroll - they act rationally, filtering content and making decisions without distraction. This means that even the commercial infrastructure of the digital economy, built around human psychology, turns out to be ill-adapted to the agentic reality, which may prompt a transition to fundamentally different business models - subscriptions, utility-based pricing, or machine-to-machine APIs. The question arises whether a specific logic of machine-to-machine interaction will emerge in the future, similar to that studied in behavioural economics for human agents. If algorithmic agents interact with each other to generate economic value, their «behavior» is subject to laws that are not described by either the classical theory of rational choice (since agents are not people) or the theory of automatic control (since they have adaptive properties). The study of this intermediate zone may become a priority area of economic theory in the coming years. Digital agents do not consume in the classical sense - they do not require food, clothing or housing. However, they consume energy, and the scale of this consumption is expanding rapidly. Computing systems, data centres, and algorithmic infrastructures form a specific resource profile that determines the material preconditions for the existence of an algorithmic population.

Estimates of global electricity consumption demonstrate the growing material footprint of digital infrastructures. Global electricity consumption by data centres is assessed at several hundred terawatt-hours annually, accounting for a notable share of total global electricity demand, and is projected to grow substantially over the current decade as digitalisation intensifies (International Energy Agency, 2025). Under baseline scenarios, data centre electricity consumption is expected to increase significantly by 2030, reaching levels comparable to those of major industrialised economies. This expansion is characterised by exceptionally high growth rates that substantially exceed overall growth in global electricity demand *(International Energy Agency, 2025).*

Artificial intelligence is emerging as the primary driver of this growth. The share of energy consumption attributable to AI workloads is projected to increase sharply over the coming years, reflecting the rapid scaling of computationally intensive models and the proliferation of AI-enabled services. At the same time, the energy requirements of individual processing units are rising due to the increasing complexity and performance demands of advanced AI systems, intensifying energy consumption across digital infrastructures *(Deloitte, 2024).*

Within the proposed analytical framework, the resource characteristics of an algorithmic agent may be formalised as an agent energy profile (AEP). AEP is defined as the specific annual volume of electricity consumption required to sustain the functioning of a cognitive full-time equivalent unit. Analogous to historical calculations of the resource requirements necessary to maintain draft animals in early transport systems, the AEP concept enables the quantification of the energy cost of maintaining an algorithmic worker and allows for systematic comparison with the resource costs associated with sustaining human labour, thereby providing a basis for analysing the material constraints of an expanding algorithmic population.

AEP will vary depending on the type of cognitive tasks (model training requires significantly more energy than inference), on the hardware architecture and on the energy efficiency of a particular data center. However, the very principle of linking resource consumption to a unit of productivity allows: (1) to compare the efficiency of different algorithmic agents in single coordinates (productivity in cFTE relative to costs in AEP); (2) to assess the total resource load of the algorithmic population on the energy infrastructure; (3) to form the basis for regulatory decisions regarding the energy intensity of algorithmic agents.

Thus, in parallel with human demography, a resource dimension of the algorithmic population emerges, which determines new material limits to growth. The economy begins to support a parallel population of digital "workers" who are neither born nor age, but constantly convert energy into productivity. This fundamentally changes the structure of investment: instead of investing primarily in the reproduction of human capital *(education, healthcare, social security),* economies begin to invest in the reproduction of computational capital *(data centers, energy infrastructure, semiconductor supply chains).* Accordingly, energy infrastructure becomes a strategic resource of comparable importance to human capital, significantly altering the priorities of public policy.

One of the most acute consequences of the transformation described is the gap between the institutional architecture of societies and the new economic reality. Modern institutions - from pension and taxation systems to models of education and political representation - were formed in the context of demographic growth and mass employment. They are built on the assumption that each succeeding generation will be larger (or at least comparable) than the previous one, that the majority of adults will work for wages, and that the tax base will be determined by the number of people employed.

The agent economy consistently undermines each of these assumptions. The World Economic Forum's Future of Jobs Report, 2025, notes that up to 92 million jobs could be eliminated by 2030, while about 170 million new ones will be created *(WEF, 2025)*. However, these replacements are not symmetrical: the new jobs do not appear in the same locations, require different skills, and will not go to the same people. The problem of asymmetric substitution is not new. It has accompanied every technological system since the Industrial Revolution and already has a well-established methodological basis. However, classical economic theories that assume the replacement of one unit of labour by another, equivalent one, systematically underestimate the qualitative heterogeneity of new and eliminated jobs. The inability to adequately respond to the asymmetric substitution is, to some extent, a consequence of the use of models in which labour is treated as a homogeneous factor, and one «unit of labour» is assumed to be replaceable by an identical one. The current wave of algorithmization exacerbates this problem: AI-related skills increase wages by 56%, while professions without AI-competences stagnate or lose their positions *(WEF, 2025),* which effectively means a bifurcation of the labour market. At the same time, participation in adult retraining programs remains consistently low, and employers are aware that employees often change jobs after acquiring new skills.

The issue of pension systems becomes particularly acute under conditions of algorithmic substitution, as solidarity-based systems require a stable or expanding base of contributors, while labour-centred taxation regimes risk losing their fiscal foundation as algorithms increasingly replace human workers. When algorithmic agents substitute for employees who would otherwise pay social contributions, corporate productivity may grow alongside a simultaneous erosion of the fiscal base necessary for social reproduction. In this context, the category of cognitive full-time equivalent acquires not only analytical but also regulatory significance. If algorithmic agents are assigned identifiable productivity metrics and registered within a dedicated identification framework, it becomes possible to introduce discrete taxation of algorithmic employment, whereby each cognitive full-time equivalent replacing human labour generates a contribution to pension and social funds comparable to that associated with a human worker. Such an approach would establish a direct link between the scale of algorithmic substitution and the financing of social security systems, thereby reducing firms' capacity to externalise the social costs of automation. The adaptation of economic and regulatory infrastructures to the emergence of algorithmic agents as economic actors thus becomes a necessary condition for maintaining the sustainability of existing social protection and redistribution systems *(Shahidi et al., 2025).*

A separate analytical issue is the ability of digital agents not only to participate in market processes, but also to deform them. Collusion (from the Latin *«collusion» - conspiracy*) in economic theory means the coordinated behaviour of competitors, which leads to maintaining prices above the competitive level. Traditionally, collusion has been viewed as the result of explicit or tacit agreements between human agents with bounded rationality. One of the most significant empirical discoveries of recent years concerns algorithmic collusion - the ability of independent artificial intelligence agents to coordinate supra-competitive prices in repeated pricing games. Evidence shows that reinforcement learning algorithms can "learn" collusive strategies even without explicit programming for such behaviour, demonstrating the potential for autonomous coordination among digital agents *(Calvano et al., 2020).* Subsequent empirical analysis based on real market data confirms that the introduction of algorithmic pricing mechanisms may be associated with observable price increases in competitive markets, highlighting the practical relevance of this phenomenon *(Assad et al., 2024; Panchenko et al., 2024).*

This development has profound theoretical implications. Classical competition theory is grounded in the assumption of human agents characterised by bounded rationality, information asymmetry and coordination constraints. Algorithmic agents may partially overcome these limitations, necessitating a reconsideration of antitrust regulation and traditional interpretations of market failure. Research suggests that collusive outcomes may emerge from structural properties of reinforcement learning systems themselves, particularly from insufficient exploration within learning processes, and that increased exploration can lead to pricing outcomes closer to competitive benchmarks *(Abada & Lambin, 2023).* This indicates that the core issue lies less in intentional collusion than in the systemic characteristics of learning algorithms, thereby requiring new forms of regulatory and analytical response.

Within the conceptual framework of shadow demography, algorithmic collusion acquires an additional dimension. The expansion of the algorithmic population implies that a growing share of market decisions will be made by agents capable of coordination beyond the scope anticipated by classical competition theory. This dynamic creates a novel type of market failure that calls not only for adjustments in antitrust practice but also for a broader reconsideration of the theoretical foundations of competition in an economy increasingly shaped by autonomous digital agents.

The described transformation has a distinct geopolitical dimension. The ability to create, maintain and control algorithmic agents is unevenly distributed. According to available estimates, North America accounts for a substantial share of the global AI agent market, reflecting the concentration of technological capabilities and digital infrastructure in advanced economies *(Klover.ai, 2025).* The United States and China together are projected to account for the overwhelming majority of the increase in electricity consumption by data centres by 2030, demonstrating the geographical concentration of the material infrastructure required to sustain the algorithmic economy *(IEA, 2025).* At the same time, the exposure of labour markets to generative artificial intelligence differs significantly across income groups: the share of jobs potentially affected by generative AI reaches approximately one-third in high-income economies compared to significantly lower levels in low-income countries *(World Economic Forum, 2025).*

This indicates that the decoupling between demographic dynamics and economic growth is uneven across countries. Advanced economies facing demographic ageing have the opportunity to compensate for labour force decline by deploying algorithmic agents. Developing countries with young and growing populations risk the erosion of their demographic advantage: if cognitive labour can be reproduced algorithmically, the traditional demographic dividend may transform into a demographic burden. Such a scenario has been anticipated in analyses of the global distributional consequences of artificial intelligence and technological change, which emphasise the risk that countries relying on labour cost advantages may lose their development trajectory as production and service functions become increasingly automated *(Korinek & Stiglitz, 2021).* This dynamic can reverse the traditional logic of comparative advantage and contribute to the emergence of new forms of technologically driven international inequality.

Competition for the energy resources required to sustain an algorithmic population introduces an additional dimension of international rivalry. Electricity production becomes an indicator not only of industrial capacity but also of the ability to maintain algorithmic infrastructure. The scale of this challenge is illustrated by the substantial energy requirements of large-scale artificial intelligence computing clusters, which demand electricity levels comparable to those of major industrial or urban consumers. Countries with constrained energy resources risk remaining on the periphery of the emerging algorithmic economy, even when they possess significant human capital in information technology. The parallel development of humanoid robotics reinforces this trend. As the cost of producing humanoid systems with functional capabilities comparable to human labour approaches the total cost of training a skilled worker, countries with advanced industrial bases acquire the capacity to expand their productive «population» through robotic manufacturing. Projections by technology firms indicate the possibility of mass-producing humanoid units at costs comparable to or lower than the lifetime investment in human capital formation, transforming industrial capacity into a functional demographic resource. In this perspective, enterprises built on predominantly robotic production systems may achieve productivity levels significantly exceeding those of firms relying primarily on human labour, further intensifying structural asymmetries within the global economy.

In the middle of this spectrum are countries like Ukraine, for which the issue of algorithmic demography is particularly acute. On the one hand, Ukraine is experiencing an unprecedented demographic crisis, exacerbated by migration and the consequences of armed conflict. On the other hand, it has significant human capital in the IT sector and the potential for integration into global chains of algorithmic production. The strategic issue for such countries is not so much in counteracting algorithmic substitution as in developing their own capacity to create, control and regulate digital agents, as well as in providing the energy infrastructure to support them.

The academic nature of the article obliges consideration of counterarguments. Is it correct to consider digital agents as functional equivalents of economic entities? Isn't this excessive «anthropomorphization»? Critics may argue that agents have no self-interest, do not make decisions in the full sense of the term, and are not responsible for their actions. They remain objects of ownership and control by human or corporate entities. In the legal sense, they are not subjects of law, do not enter into contracts in their own name, and do not possess legal capacity. These objections are well-founded. However, they do not refute the central thesis; rather, they refine it. Functional equivalence does not imply ontological identity. A corporation is also not a human being, yet it is recognised as a subject of economic and legal relations. The legal fiction of corporate personality emerged precisely because the functional role of corporations in economic processes required appropriate institutional formalisation. Similarly, the growing role of digital agents in production, exchange, and distribution may eventually necessitate new institutional frameworks even if these frameworks do not involve granting agents full legal personality.

Current technological trajectories suggest the potential emergence of a global economy in which autonomous artificial intelligence agents interact with one another to generate economic value independently of human labour (*Shahidi, Rusak, Manning, Fradkin & Horton, 2025).* This differs fundamentally from previous technological transformations. Historically, technological progress was driven by relatively inflexible inventions that sequentially increased productivity in specific sectors *(Mokyr, Vickers & Ziebarth, 2015).* Artificial intelligence agents, by contrast, assume the form of "flexible capital" capable of automating diverse cognitive tasks across industries and professions *(Eloundou, Manning, Mishkin & Rock, 2024).*

The Digital Economic Agent Identification *(DEAI)* system proposed in this article represents an institutional solution that does not grant legal personality to agents but ensures their visibility for regulatory and statistical systems. Just as the registration of companies does not imply that a legal entity is a human being but merely records its existence and activity, the registration of algorithmic agents would document their economic functionality. In the longer term, it may prove appropriate to require the discrete registration of software complexes by functionally separating them into identifiable units for regulatory purposes, in a manner analogous to the possibility of compulsory corporate division within antitrust law.

A historical perspective is useful for understanding the transformation described. Each of the great technological revolutions changed the relationship between population and production. The agricultural revolution loosened the Malthusian trap, allowing population growth without a commensurate increase in hunger. The industrial revolution transformed the very nature of growth: rapid technological progress became its key engine, accompanied by reproducible capital in the form of machines and factories *(Korinek, 2024)*. As technology and capital accumulated, labour became the bottleneck. It was this labour scarcity that led to a significant increase in wages, creating the current level of well-being that has increased approximately twentyfold in advanced economies since the Industrial Revolution. The digital revolution may mark another paradigm shift, making human intelligence reproducible *(Korinek & Suh, 2024)*. Artificial intelligence systems and robots have the potential to replace both cognitive and physical human labour. In this new era, both traditional capital and intelligent machines are becoming reproducible resources, and the line between them is increasingly blurred.

However, each of the previous revolutions generated new forms of employment that compensated for those displaced. Predictions that technology would reduce the need for human labour have a long history but uneven empirical confirmation, as technological change has historically created new forms of employment even as it displaces existing ones *(Goldman Sachs Research, 2025)*. The question that remains unanswered is whether the digital revolution will follow this pattern, or whether artificial intelligence capabilities will advance so rapidly that even newly created occupations will be performed more efficiently by machines than by humans.

The degree of divergence in expert opinion on this issue is extraordinary. Analytical assessments of the labour market effects of artificial intelligence indicate that a significant proportion of researchers and technology developers consider large-scale substitution of human labour by artificial intelligence within the coming years to be a plausible scenario (*Brynjolfsson, Chandar & Chen, 2025)*. At the same time, leading technology companies are incorporating into their strategic planning scenarios of extensive robotization of production processes within the next decade, including the mass production of humanoid robots and the deployment of digital workers capable of performing a wide range of cognitive tasks traditionally associated with human labour (*McKinsey Global Institute, 2025)*. Within the analytical framework of the present study, the direction and speed of these technological trajectories, as perceived by the actors who create and deploy these technologies, constitute empirically significant indicators of structural transformation.

Conclusions. The article proposes a conceptual framework for analysing digital agents as functional equivalents of an economic subject, enabling us to identify a fundamentally new situation for economic theory: the disconnect between demographic dynamics and economic growth, which for millennia seemed axiomatic. First, it is substantiated that the change in the ontological status of technology - from a tool for increasing productivity to an autonomous participant in economic processes - forms a hybrid factor of production *(«agent capital»)*, which does not fit into the classical triad of factors of production and requires a rethinking of the fundamental categories of economic theory. Second, a paired categorical construct is proposed: shadow demographics, which describes the current unobserved state of the algorithmic population, and algorithmic demographics as a promising state arising from the institutionalization of accounting for digital agents. An approach to the quantitative identification of algorithmic agents is developed through the categories of cognitive full-time equivalent (cFTE) and agent energy profile (AEP), and the concept of digital economic agent identification (DEAI) as an institutional mechanism for the transition from shadow to algorithmic demography. Thirdly, it is shown that a fundamental asymmetry arises between economic and social reproduction: digital agents can compensate for the population's production functions but cannot replace its social reproduction functions, leading to a divergence between the logic of production and the logic of the social order. Fourthly, it is substantiated that the institutional architecture of modern societies is built on assumptions that are systematically undermined by the agent economy. The concept of discrete taxation of algorithmic employment is proposed as a mechanism to preserve the fiscal base of social protection amid algorithmic substitution. Fifthly, the geoeconomic dimension of algorithmic transformation is analysed, within which the ability to create, maintain and control digital agents becomes a new axis of international inequality. It is shown that developed economies can potentially compensate for demographic aging through algorithmic substitution, whereas in developing countries, the demographic dividend risks being devalued. For countries with an intermediate status, such as Ukraine, the strategic priority is to develop their own capacity to create and control digital agents, as well as to provide the energy infrastructure to support them. Economic power is no longer measured solely by population size. It is increasingly determined by the ability to create, maintain, and control technological agents. This does not mean devaluing human life or human labour as such, but it does mean the need for a radical revision of the categorical apparatus that economists, demographers, and politicians operate. Bridging the gap between economic logic that adapts to algorithmic reality and social institutions that remain built on the assumption of demographic growth is one of the central tasks of economic theory and policy in the 21st century.

Funding: *no external funding.*
Conflict of Interest: *Natalia Reznikova is the Editor-in-Chief of the journal "Actual Problems of International Relations". To ensure a transparent and objective process, this manuscript was handled by other members of the Editorial Board and underwent independent peer review. The author was not involved in any editorial decisions regarding the acceptance of this paper.*
Data Availability Statement: *not applicable*

References:

Abada, I., & Lambin, X. (2023). Artificial Intelligence: Can Seemingly Collusive Outcomes Be Avoided? *Management Science, 69*(9), 5042-5064. http://dx.doi.org/10.2139/ssrn.3559308

Acemoglu, D. (2024). The simple macroeconomics of AI (NBER Working Paper No. 32487). *National Bureau of Economic Research*. https://www.nber.org/system/files/working_papers/w32487/w32487.pdf

Acemoglu, D., & Restrepo, P. (2018). The race between man and machine: Implications of technology for growth, factor shares, and employment. *American Economic Review, 108*(6), 1488-1542. https://doi.org/10.1257/aer.20160696

Assad, S., Clark, R., Ershov, D., & Xu, L. (2024). Algorithmic Pricing and Competition: Empirical Evidence from the German Retail Gasoline Market. *Journal of Political Economy, 132*(3), 723-771. https://www.ifo.de/en/cesifo/publications/2020/working-paper/algorithmic-pricing-and-competition-empirical-evidence-german

Becker, G. S. (1964). Human Capital: A Theoretical and Empirical Analysis, with Special Reference to Education. New York: Columbia University Press.

Bengio, Y., Hinton, G., Yao, A., Song, D., Abbeel, P., Darrell, T., Harari, Y. N., Zhang, Y. Q., Xue, L., Shalev-Shwartz, S., Hadfield, G., Clune, J., Maharaj, T., Hutter, F., Baydin, A. G., McIlraith, S., Gao, Q., Acharya, A., Krueger, D., … Mindermann, S. (2024). Managing extreme AI risks amid rapid progress. *Science*, 384(6698), 842-845. https://www.science.org/doi/10.1126/science.adn0117

Brynjolfsson, E., Chandar, B., & Chen, R. (2025). Canaries in the coal mine? Six facts about the recent employment effects of artificial intelligence (SIEPR Working Paper). Stanford Institute for Economic Policy Research. https://siepr.stanford.edu/publications/working-paper/canaries-coal-mine-six-facts-about-recent-employment-effects-artificial

Calvano, E., Calzolari, G., Denicolò, V., & Pastorello, S. (2020). Artificial Intelligence, Algorithmic Pricing, and Collusion. *American Economic Review, 110(*10), 3267-3297. DOI: 10.1257/aer.20190623

Deloitte (2025). AI data center power demand could surge 30x by 2035 amid power and grid capacity constraints. *Deloitte Insights*. https://energynow.com/2025/06/deloitte-ai-data-center-power-demand-could-surge-30x-by-2035-amid-power-and-grid-capacity-constraints/

Eloundou, T., Manning, S., Mishkin, P., & Rock, D. (2024). GPTs are GPTs: Labour market impact potential of LLMs. *Science*, 384(6702), 1306-1308. https://www.science.org/doi/10.1126/science.adj0998

Goldman Sachs Research (2025). *The Potentially Large Effects of Artificial Intelligence on Economic Growth*. GS Global Economics Research. https://www.gspublishing.com/content/research/en/reports/2023/03/27/d64e052b-0f6e-45d7-967b-d7be35fabd16.html

Hargrove, J. L. (2006). History of the Calorie in Nutrition. *The Journal of Nutrition, 136*(12), 2957-2961. https://doi.org/10.1093/jn/136.12.2957
https://doi.org/10.17721/apmv.2020.143.1.85-95

International Energy Agency (2025). *Electricity 2025*. Paris: IEA.

https://www.iea.org/reports/electricity-2025

Klover.ai (2025). AI Agents Reshape Capitalism: Agentic Economy Challenges Status Quo. Research Report. https://www.klover.ai/ai-agents-reshape-capitalism-agentic-economy-challenges-status-quo

Korinek, A. (2024). Economic policy challenges for the age of AI (NBER Working Paper No. 32980). *National Bureau of Economic Research*. https://www.nber.org/papers/w32980

Korinek, A., & Stiglitz, J. E. (2021). Artificial intelligence, globalization, and strategies for economic development (NBER Working Paper No. 28453). *National Bureau of Economic Research*. https://www.nber.org/papers/w28453

Korinek, A., & Suh, D. (2024). Scenarios for the transition to AGI (NBER Working Paper No. 32255). *National Bureau of Economic Research*. https://www.nber.org/system/files/working_papers/w32255/w32255.pdf

Kremer, M. (1993). Population growth and technological change: One million BC to 1990. *The Quarterly Journal of Economics*, *108*(3), 681-716. https://doi.org/10.2307/2118405.

McKinsey Global Institute (2025). Agents, Robots, and Us: Skill Partnerships in the Age of AI. MGI Report.

Mokyr, J., Vickers, C., & Ziebarth, N. (2015). The history of technological anxiety and the future of economic growth: Is this time different? *Journal of Economic Perspectives, 29*(3), 31-50. https://prawo.uwr.edu.pl/wp-content/uploads/sites/210/2022/08/Mokyr-is-this-time-different.pdf

Ozkan, S., & Sullivan, N. (2025, August 26). Is AI contributing to rising unemployment? Evidence from occupational variation. *On the Economy Blog*, Federal Reserve Bank of St. Louis. https://www.stlouisfed.org/on-the-economy/2025/aug/is-ai-contributing-unemployment-evidence-occupational-variation

Panchenko, V. H., Reznikova, N. V., Ivashchenko, O. A., & Rusak, D. M. (2024). Hih-ekonomika yak seredovyshche transformatsii mizhnarodnoho rynku pratsi [Gig economy as an environment for transformation of the international labour market]. *Investytsii: praktyka ta dosvid*, 4, 12-18. https://doi.org/10.32702/2306-6814.2024.4.12 [in Ukrainian].

Panchenko, V. H., Reznikova, N. V., Ptashchenko, O. V., & Ivashchenko, O. A. (2024). Tsyfrovi transformatsii mizhnarodnoho rynku pratsi v umovakh platformizatsii zainiatosti [Digital transformations of the international labor market in the conditions of employment platformization]. Efektyvna ekonomika, 2. https://www.nayka.com.ua/index.php/ee/article/view/3063/3099 [in Ukrainian].

Pryiatelchuk, O. A. (2017). Sotsializatsiia suchasnoi systemy derzhavnoho ta korporatyvnoho upravlinnia [Socialization of modern system of state and corporate management]. *Economy and Society*, 9. [in Ukrainian].

Pryiatelchuk, O. A. (2023). Tsyfrova torhivlia na hlobalnykh rynkakh: Tendentsii ta vyklyky [Digital trade in global markets: Trends and challenges]. *Zhurnal stratehichnykh ekonomichnykh doslidzhen, 4*(15), 50-56. [in Ukrainian].

Pryiatelchuk, O. A., & Bekh, A. A. (2020). Conceptualization of the digital media market in the context of the world economy. Actual Problems of International Relations, 143(1), 85-95.

Pryiatelchuk, O., & Naida, O. (2025). Human capital as a fundamental intangible asset of international business. *Actual Problems of International Relations, 164*(1), 192-201. https://doi.org/10.17721/apmv.2025.164.1.192-201

Rabinbach, A. (1990). The Human Motor: Energy, Fatigue, and the Origins of Modernity. New York: BasicBooks.

Reznikova, N., & Ivashchenko, O. (2017). Nova normalnist hlobalnoi ekonomiky: zmist ta sutnisni kharakterystyky hlobalnykh ryzykiv u konteksti neozalezhnosti [New normal of the global economy: The meaning and essential characteristics of global risks in the neo-dependence context]. *Investytsiyi: praktyka ta dosvid,* 9, 5-10. http://www.investplan.com.ua/pdf/9_2017/3.pdf [in Ukrainian].

Reznikova, N., & Panchenko, V. (2023). Reportazhi iz tsyvilizatsiinykh frontiv. Na peredovii mizhnarodnoi ekonomichnoi polityky [Reports from civilizational frontlines. On the frontline of international economic policy]. Kyiv: Ahrar Media Hrup. [in Ukrainian].

Reznikova, N., Bulatova, O., Ptashchenko, O., Ivashchenko, O., & Panchenko, V. (2023). Zowning and Z-consumption in the conditions of movement from shareholder to stakeholder capitalism: Values as the basis of self-identification. *Investytsiyi: praktyka ta dosvid,* 5, 28-36. https://doi.org/10.32702/2306-6814.2023.5.28[in Ukrainian].

Reznikova, N., Ptashchenko, O., & Ptashchenko, L. (2025). Beyond Industry 4.0 and competition: Data and information technology markets as a battlefield for digital leadership. *Actual Problems of International Relations, 163*(1), 152-166. https://doi.org/10.17721/apmv.2025.163.1.152-166

Reznikova, N., Ptashchenko, O., Chugayev, O., & Ivashchenko, O. (2023). Y-reality as a shift from "great moderation" to "global chaos": Assessment of global macroeconomic and crisis processes through the prism of generational dialogue and development issues. *Journal of Strategic Economic Research, 6,* 67-78. https://doi.org/10.30857/2786-5398.2022.6.6

Rubtsova, M. Yu., & Reznikova, N. V. (2018b). Problema samovyznachennia liudyny ta pohlyblennia yii kompetentsii v umovakh inkliuzyvnoho rozvytku svitovoho hospodarstva: zviazok z hlobalnymy problemamy liudstva [The problem of human self-determination and deepening of competencies in the conditions of inclusive development of the global economy: The relationship with global problems of humanity]. *Efektyvna ekonomika*, 8. http://www.economy.nayka.com.ua/?op=1&z=6633 [in Ukrainian].

Rubtsova, M., & Reznikova, N. (2018a). Problema pidvyshchennia produktyvnosti pratsi liudyny ta rozvytku yii kompetentsii v umovakh robotyzatsii u vyrobnychii ta sferi posluh [The problem of human labour productivity enhancement and the development of competencies in the conditions of robotization in production and service sectors*]. Efektyvna ekonomika*, 9. [in Ukrainian].

Shahidi, P., Rusak, G., Manning, B., Fradkin, A., & Horton, J. J. (2025). The Coasean singularity? Demand, supply, and market design with AI agents. *NBER Working Paper No. 34468*. National Bureau of Economic Research.

Trammell, P., & Korinek, A. (2023). Economic growth under transformative AI (NBER Working Paper No. 31815). *National Bureau of Economic Research.* https://www.nber.org/system/files/working_papers/w31815/w31815.pdf

Vergun, V. A. (Ed.). (2020). Mizhnarodnyi biznes: Dlia studentiv neekonomichnykh spetsialnostei zakladiv vyshchoi osvity Ukrainy [International business: For students of non-economic specialties of higher education institutions of Ukraine]. Kyiv: VADEX. [in Ukrainian].

World Economic Forum (2025). The Future of Jobs Report 2025. Geneva.

Received: 12.02.26 / Revised: 24.02.26 / Accepted: 18.03.26 / Published:30.03.26