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The Innovation and Ecological Formation of New Quality Productive Forces Driven by the Digital Economy

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Abstract. This article comprehensively explores the connotations and characteristics of the digital economy and new productivity, as well as their mutually empowering, spiraling, and deeply integrated relationship. It also analyzes the innovation-driven mechanisms of the digital economy on new productivity through the three dimensions of technological innovation, industrial upgrading, and value creation. By constructing an indicator system for new productivity and the digital economy and determining their weights, building a regression model, and conducting empirical analysis, we ultimately establish a quantitative relationship between the digital economy's impact on new productivity and identify its key driving forces. Based on this research, we offer policy recommendations to promote the integrated development of the digital economy and new productivity.

Keywords: Digital economy; new productivity; innovation-driven.

1. Introduction

Digital technology is developing rapidly and penetrating widely. The digital economy has become an important driving force for the leap of social productivity and structural change. New-quality productivity is a new type of productivity that relies on scientific and technological innovation as the primary driving force and emphasizes high quality, high efficiency and sustainable development. Its cultivation and development increasingly rely on the in-depth integration and system empowerment of the digital economy. Existing research reveals that the digital economy has multi-faceted impacts from different perspectives. Luo Shuangcheng focuses on the positive impact of the digital economy on economic development [1]. The digital economy has a promoting effect on economic development, can optimize factor allocation, and has stronger factor mobility within and across regions, which can promote the level of market integration and the speed of upgrading. Liu Ruiming and Xu Yuan explain the impact of the digital economy on the economy from the perspective of opportunities and challenges [2]. The opportunities brought by the digital economy are mainly the contribution of the digital economy to economic growth and the positive impact on promoting employment and infrastructure construction. At the same time, they put forward the existence of the digital divide and the imbalance of regional economic development. The development of the digital economy has great potential to drive industrial upgrading and economic growth. The digital economy also faces structural problems that need to be systematically addressed. In this context, the mechanisms through which the digital economy influences new productivity, and whether the inherent logical relationship between the two is one-way transmission or two-way interaction, are topics that require research. Current research has yet to provide a systematic theoretical response and empirical explanation for these questions, and a more in-depth and integrated exploration is needed. Current research often focuses on a single dimension of the digital economy, such as digital industrialization, and its local impact on production efficiency or innovation performance, lacking a holistic analytical framework from a systems and dynamic perspective. Furthermore, theoretical exploration of new productivity is still in its early stages, and its conceptual connotations, measurement systems, and formation mechanisms require further clarification. Against this backdrop, in-depth exploration of the inherent connections and mechanisms between the digital economy and new productivity will not only enrich modern productivity theory but also be crucial for grasping the new driving forces of the digital age and building a modern industrial system.

2. Overview of the Digital Economy and New Productivity

The digital economy and new productivity are not parallel entities; rather, they are mutually empowering and spirally integrated. The digital economy provides fundamental support for new productivity: big data drives precise decision-making, artificial intelligence enhances automation and intelligence, the industrial internet enables efficient cross-enterprise and cross-regional resource collaboration, and technologies like digital twins and intelligent sensing reshape production processes, significantly improving productivity and innovation. New productivity is driving the in-depth development of the digital economy: cutting-edge technological breakthroughs in quantum computing, 6G communications, brain-computer interfaces, and advanced algorithms are continuously expanding the application boundaries of digital technology, driving the digital economy from "connectivity" to "intelligence." The deep integration of the two will not only accelerate the transformation and upgrading of traditional industries but also give rise to new industries, new business forms, and new models. It will become a core path to building a modern industrial system and achieving effective qualitative improvement and reasonable quantitative growth in the economy.

3. The digital economy’s innovative driving mechanism for new productivity

3.1. Technological innovation drive

Digital technology, as the core driving force of innovation, is reshaping the social innovation ecosystem by reconstructing the innovation paradigm, optimizing resource allocation and stimulating the vitality of the subject.

3.1.1. Digital technology promotes technological innovation and transformation

The popularization of digital technologies such as artificial intelligence, big data, and blockchain is fundamentally changing the "production mode" of scientific and technological innovation, making it more efficient, more economical and more groundbreaking.

In terms of improving innovation efficiency, the role of artificial intelligence is more significant. Artificial intelligence replaces repetitive scientific research work and shortens the R&D cycle. For example, farmers can quickly identify crop diseases and pests by taking photos of leaves through the image recognition function of mobile phone apps, without having to wait for experts to diagnose on the spot, which greatly improves the recognition efficiency. This is consistent with Brynjolfsson's view of "AI as an innovation accelerator" in "The Turing Trap" [3], that is, AI is not only an innovation itself, but also can trigger a series of complementary innovations. It directly improves productivity by reducing the consumption of manpower in dangerous and boring tasks through automation, freeing up manpower and resources for innovation.

3.1.2. Stimulating the Vitality of Innovators

The digital economy has created a new development environment for various innovators, lowering the threshold for innovation and accelerating iteration, prompting businesses and research institutions to continuously adapt and proactively innovate.

In terms of enhancing corporate innovation momentum, digital tools have effectively lowered the barrier to innovation for small and medium-sized enterprises. Previously, small furniture workshops relied on designers to draw hand-drawn blueprints and then promote new products through offline exhibitions. This was time-consuming and costly, leading to slow product updates. After connecting to a cloud-based design platform, workshops utilize the platform's modular furniture model library and 3D rendering tools. Designers can instantly create new designs by simply modifying basic parameters, significantly improving design efficiency. Furthermore, the platform's built-in social sharing features allow new products to be immediately presented to end consumers, broadening market reach and significantly reducing promotion costs. This example confirms the view expressed by Teece et al. in their study of dynamic capabilities and strategic management - the dynamic capabilities theory focuses on the integration, construction and reconstruction of internal and external capabilities of enterprises to cope with rapidly changing environments [4]. The article mentions that organizational processes, asset arrangements and development paths together form the competitive advantage of enterprises. Digital tools are stimulating the innovation vitality of small and medium-sized enterprises from three perspectives: process improvement, resource reorganization and path transformation. Cloud platforms provide modular tools, reduce the threshold of design capabilities, social media add dissemination channels, reduce dependence on traditional resources, and rapid iteration models change the innovation path, thereby increasing the speed at which enterprises respond to the market.

3.2. Driving Industrial Upgrading

The digital economy fosters emerging industries, drives the transformation of traditional industries, optimizes the overall industrial structure, promotes the exchange of old and new drivers of growth, builds a new path for industrial upgrading, and provides strong industrial support for the development of new-quality productivity.

3.2.1. Driving Emerging Industries

The digital economy breaks down the spatial and temporal boundaries of traditional industries. Data empowerment and platform-based operations are driving the emergence of emerging industries such as intelligent connected services for new energy vehicles. Its "precise matching of supply and demand + lightweight operations" model creates new growth points and reshapes the value landscape. When companies leverage connected vehicle platforms to collect vehicle data, use big data analysis to provide battery maintenance and charging planning services, and collaborate with operators to achieve dynamic scheduling, they significantly improve charging efficiency and generate substantial service revenue without requiring the construction of large-scale offline outlets. This is consistent with the research of Li Xiaomin, Zhang Ce, and Li Dongkun in "The Impact of Digital Economy on Technological Innovation in the New Energy Vehicle Industry" [5], which states that the digital economy can integrate industrial chain resources, optimize supply and demand efficiency, and promote the transformation of the new energy vehicle industry towards the "three transformations" of intelligence, networking, and electrification. It can also give rise to emerging business models and introduce new roles such as technology service providers, thus reshaping the traditional interest structure.

3.2.2. Promoting the digital transformation of traditional industries

Digital technology digitally reconstructs the production factors of traditional industries, and the manufacturing, agriculture, and service industries have achieved systematic upgrades in production processes, management models, and market access methods, thereby improving total factor productivity. In the manufacturing industry, BMW Group's Dingolfing plant uses digital twin technology to simulate the automobile production process in a virtual environment, improve the process in advance, shorten the mass production time of new models, and reduce the cost of production line adjustment. In agriculture, some Australian farms rely on satellite images and machine learning algorithms to observe the growth of crops, accurately spray pesticides and fertilizers, reduce pesticide use, and increase crop yields. In the service industry, Marriott Hotel Group uses data to analyze customer accommodation habits, provide personalized services, and improve customer satisfaction and room reservation rates. As Michael E. Porter et al. have studied in their research on how connected products change competition through intelligence [6], smart connected products have broken through the boundaries of traditional industries by integrating physical components, smart components, and connectivity capabilities. Their core value lies not in the optimization of a single link, but in the systematic optimization brought about by data collaboration across the entire chain. This is also the underlying logic of the digital transformation of traditional industries.

4. Empirical Analysis of the Digital Economy Driving the Development of New Productivity

4.1. Research Design

The construction, weighting, and regression analysis of the new productivity and digital economy indicator system were conducted based on relevant data from the China Statistical Yearbook. First, we collected raw indicator data for the new productivity and digital economy sectors. Based on this data, we calculated seven secondary indicators for the new productivity sector (Table 1) and five secondary indicators for the digital economy (Table 2). To determine indicator weights, we used the coefficient of variation method: The coefficient of variation $V_i=\sigma_i/\overline{X}_i$ was calculated by comparing the standard deviation (σ_i) of each indicator to the mean ($\overline{X}_i$). The weights for each dimension were then calculated using Formula $W_i=V_i/\sum V_i$ to ensure that the weights reflected the inherent variability of the indicator.

Table 1 Evaluation indicators of new quality productivity

Secondary Indicators	Calculation Method
Number of Scientific Research Enterprises per 10,000 People (units/10,000 people)	Number of Legal Entities in the Information Transmission, Computer Services, and Software Industries/Total Population (10,000 people)
Proportion of Science and Technology Expenditure (%)	Science Expenditure/Fiscal Expenditure
Number of Authorized Patents per 10,000 People (units/10,000 people)	Number of Patent Authorizations/Total Population (10,000 people)
Number of Scientific Research Employees per 10,000 People (people)	Number of Employees in Information Transmission, Software, and Information Technology/Total Population (10,000 people)
GDP Per Capita (RMB/person)	Total GDP/Total Population
Average Wage of Employed Employees (RMB/person)	-
Proportion of Environmental Governance Investment in GDP	Investment in Environmental Pollution Control (RMB 100 million)/GDP (RMB 1 billion)

Table 2 Digital economy evaluation indicators

Indicator	Calculation Method
Number of Mobile Internet Users	Number of Internet Users per 100 Population
Mobile Phone Penetration Rate	-
Number of Scientific Research Enterprises per 10,000 People (units/10,000 people)	Number of Legal Entities in Information Transmission, Computer Services, and Software Industries/Total Population (10,000 people)
Number of Scientific Research Employees per 10,000 People (people)	Number of Employees in Information Transmission, Software, and Information Technology Industries/Total Population (10,000 people)
Digital Financial Inclusion Development	China Inclusive Finance Index

Subsequently, each secondary indicator value is standardized and converted into a value between 0 and 1. The formula is:

$$I_i=W_i\cdot\frac{\overline{X}_i-m_i}{M_i-m_i} \tag{1}$$

Among them, M_i and m_i are the maximum and minimum values of the i-th indicator respectively, and W_i is the corresponding weight.

Furthermore, a multi-dimensional comprehensive synthesis method was used to synthesize the seven secondary indicators of new quality productivity into a comprehensive indicator NPL, the calculation formula of which is:

$$NPL=1-\frac{\sqrt{(W_1-I_1)^2+(W_2-I_2)^2+\cdots+(W_7-I_7)^2}}{\sqrt{W_1{}^2+W_2{}^2+\cdots+W_7{}^2}} \tag{2}$$

This formula reflects the overall development level of new quality productivity.

In the regression analysis, the five secondary indicators of digital economy are used as independent variables (x_1,x_2,x_3,x_4,x_5), and the comprehensive index of new quality productivity IFI is used as the dependent variable (y), and a regression model is established：

$$y=\beta_0+\beta_1x_1+\beta_2x_2+\beta_3x_3+\beta_4x_4+\beta_5x_5+\varepsilon \tag{3}$$

The regression coefficients were obtained through fitting, and finally the quantitative relationship between the impact of the digital economy and new quality productivity was established (Table 3).

Table 3 Descriptive statistics of indicators

Variables		Mean	Standard Deviation	Minimum	Maximum
Level of new productivity	NPL	0.32	0.15	0.04	0.52
Number of mobile internet users	MIU	86.12	13.65	63.58	108.14
Mobile phone penetration rate (%)	MP	99.54	17.98	64.36	123.69
Number of scientific research enterprises per 10,000 people	SRE	5.68	4.25	1.43	13.40
Number of scientific research employees per 10,000 people	SRP	27.35	8.05	13.86	37.56
Inclusive development of digital finance	DFI	244.96	133.60	31.82	483.12

4.2. Empirical Results and Analysis

The regression results show the analysis results of the linear regression model with NPL (new quality productivity comprehensive index) as the dependent variable and the five digital economy secondary indicators of MIU, MP, SRE, SRP, and DFI as independent variables (Table 4).

Table 4 Benchmark regression results of the digital economy’s impact on new quality productivity

Variable	NPL
MIU	0.0049 (1.56)
MP	0.0066 (1.42)
SRE	-0.0376* (-2.00)
SRP	0.0223* (2.03)
DFI	-0.0004 (-0.67)
Constant	-1.0497** (-2.65)
Number of periods	14
R^2	0.9204

The following is a detailed analysis:

The coefficients, P values, and confidence intervals show significant differences in the magnitude and statistical significance of the impact of each variable on NPL.

5. Key Conclusions:

5.1. Significantly Influential Factors:

SRE (number of scientific research enterprises per 10,000 people): has a negative impact on NPL at the 10% significance level (coefficient: -0.0376). This finding contradicts theoretical expectations and may be driven by the following mechanisms:

The expansion of the number of scientific research enterprises has a significant negative impact on new-quality productivity. This is primarily due to three factors: First, the dilution effect of innovation resources: excessive dispersion of factors leads to diseconomies of scale, thus reducing overall innovation efficiency; second, innovation activities exhibit a significant time lag: R&D investment initially manifests as a cost expenditure, while economic benefits take time to materialize, resulting in a negative correlation between short-term measurement indicators; third, insufficient coordination within the innovation system, weak industrial support, and a lack of mechanisms for transforming research results lead to a structural disconnect between scientific research and economic development.

The results show that a development model that simply pursues the expansion of the number of innovative entities has shown diminishing marginal returns and may even have a suppressive effect on innovation efficiency. Therefore, policies should promote the transformation of the innovation system from scale expansion to quality improvement and establish an efficiency-oriented governance mechanism. Specifically, resources should be directed towards high-performing entities, industry-university-research collaboration and the transformation of research results should be strengthened, thereby comprehensively enhancing the competitiveness of the regional innovation ecosystem.

SRP (number of scientific research personnel per 10,000 people): At the 10% significance level, it has a positive impact on NPL (new quality productivity) (coefficient 0.0223), consistent with theoretical expectations. This indicates that R&D investment and application efficiency of digital technologies can effectively promote the development of new quality productivity. This result is consistent with theoretical expectations, indicating that investment in scientific research human resources is the main driving force for the development of new quality productivity. The greater the number of scientific research personnel per 10,000 people, the stronger the regional innovation capacity and the higher the efficiency of technology transformation, making a positive marginal contribution to productivity progress. This conclusion empirically verifies the applicability of human capital theory to digital R&D. The concentration of high-end talent is crucial for cultivating new quality productivity. Therefore, all regions should attach importance to the development of scientific research talent teams and improve the mechanisms for attracting and cultivating high-level talent.

5.2. Insignificant Factors:

The P-values for the three variables MIU (mobile internet users), MP (mobile phone penetration), and DFI (digital financial inclusion) are all greater than 0.1, indicating statistical insignificance. This indicates that, given the current sample and data, no clear linear impact of these variables on new productivity has been found.

5.3. Constant Term:

The constant term is significantly negative (-1.0497) at the 5% level, meaning that when all independent variables are zero, the predicted value of NPL is negative. This result further highlights the fundamental support provided by digital economic factors for the development of new productivity. In the absence of the core elements of the digital economy, the theoretical productivity level would be far lower than the lowest observed value in the actual sample, resulting in a significantly negative value. This finding, at a quantitative level, reinforces the core conclusion of a structural dependency between the digital economy and new productivity.

The final regression formula is:

$$NPL=-1.0487+0.0049MIU+0.0066MP-0.0376SRE+0.0223SRP-0.0004DFI \quad (4)$$

Due to the high correlation between this variable and other core explanatory variables, its independent contribution is difficult to accurately identify. In the final model estimation results, the variable "Mobile Internet Users (MIU)" was removed due to multicollinearity and did not enter the final regression equation.

When the number of mobile internet users (MIU) is removed, the results are adjusted. Researchers' input has become the core driving force behind the development of new-quality productivity (Table 5). In the model, scientific researcher density (SRP) has a significant positive impact on new-quality productivity at the 5% significance level, with a regression coefficient of 0.0303, the largest of all variables and the most statistically significant. This result highlights the crucial role of high-quality scientific research talent as a core element of innovation and indicates that the concentration of human capital is currently the most direct and effective driving force for improving new-quality productivity.

The density of scientific research enterprises exhibits an unexpected negative correlation. The estimated coefficient of scientific research enterprise density (SRE) is -0.0399 and is marginally significant at the 10% level, contrary to theoretical expectations. This finding suggests that the current increase in the number of scientific research enterprises has not effectively translated into productivity gains. Instead, it may be due to the fragmentation of innovation resources, intensified homogeneous competition, or declining management efficiency, leading to "involution," which has a certain inhibitory effect on overall innovation effectiveness.

The direct effects of basic supporting factors have not yet emerged. Mobile internet penetration (MIU) and digital finance development (DFI) fail to demonstrate a significant direct impact in the model. This suggests that the impact of these two types of infrastructure or service forms on new productivity may be more indirect, requiring more time or specific conditions to fully unlock their value.

Table 5 Regression results of the digital economy's impact on new quality productivity

Variable	NPL
MIU	0.0046 (1.40)
SRE	-0.040* (-2.02)
SRP	0.030** (3.05)
DFI	0.00003 (0.06)
Constant	-0.694** (-2.14)
Number of periods	14
R^2	0.9004

6. Policy recommendations for promoting the integrated development of the digital economy and new productivity

6.1. Strengthening the Cultivation and Recruitment of Scientific Research Talent

Empirical research shows that the number of scientific research employees per 10,000 people is the primary driver of new productivity. Strengthening talent support requires two key areas: first, optimizing the discipline layout and increasing higher education and talent development in cutting-edge fields such as artificial intelligence and digital technologies; and second, building a comprehensive vocational training system to support enterprises in digital skills training.

6.2. Promoting Digital Infrastructure Construction

Although digital infrastructure does not clearly reflect a direct effect in the model, its fundamental supporting role cannot be underestimated. We must continue to promote the construction of new infrastructure such as 5G and the Industrial Internet, expand coverage, and improve service quality and operational efficiency. We must also promote the intelligent and green development of traditional infrastructure such as transportation and energy, creating an efficient, intelligent, and environmentally friendly modern infrastructure.

6.3. Improve the Digital Financial Support System

While the development of inclusive digital finance has not passed the significance test, its role in supporting innovation cannot be ignored. Financial institutions should be supported in tailoring specialized credit, equity investment, and other financial products for technology companies. New financing methods, such as intellectual property pledge financing, should be actively promoted to address the financing difficulties faced by technology-based enterprises.

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