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Digital Economy, Industrial Structure and Income Inequality

-- Based on Cross-border Panel Data

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Abstract: As a distinctive feature of contemporary social development, digital economy will inevitably affect the typical fact of income inequality. This paper theoretically sorts out the influence mechanism between digital economy, industrial structure and income inequality, and conducts empirical research based on cross-border panel data from 49 countries from 2010 to 2020. The results show that the development of digital economy significantly alleviates income inequality. The digital economy indirectly narrows the income gap by promoting the advanced and rational industrial structure; The mitigating effect of the digital economy in countries with higher levels of income inequality is more pronounced than in countries with low levels of income inequality, but when the country's income distribution falls into extreme inequality, the positive effect of the digital economy in reducing income inequality is minimal.

Keywords: Digital economy, Industrial structure, Income inequality.

1. Introduction

As an umbrella of capital income inequality and labor income inequality, income inequality is influenced by benign forces such as education, social transfer, progressive taxation, and vicious forces such as revolutions, wars, pandemics, and state power changes[1], and its changes reflect the rise or decline of all aspects of society. The huge income gap has come into focus as data from inequality studies has increased. According to the World Inequality Lab, the richest 10% of the world's population accounts for half of global income, while the poorest half of the population has no access to 10% of global income; Those in the top 10% of global income earn nearly 31 times more per year than the bottom 50% of global income. There is no doubt that income inequality today transcends the country level as a thought-provoking global phenomenon.

According to the "2023 World Economic Situation and Prospects" report released by the United Nations, due to the impact of successive political, economic, climate and other crises, the global economic growth rate is expected to be only 1.9% in 2023, and the continued economic downturn will aggravate income inequality. As a powerful weapon to alleviate income inequality, economic development, especially the current vigorous development of the digital economy, will profoundly affect the pattern of income distribution. From the 80s of the 20th century to the present, the definition of digital economy has always reflected the changes in mainstream science and technology in different eras, from computers, the Internet to big data, cloud computing, artificial intelligence and other emerging technologies, its meaning revolves around information and communication technology and the Internet continues to expand, and the inclusive boundary indicates the huge development potential of the digital economy[2]. According to the Global Digital Economy White Paper (2022) released by the China Academy of Information and Communications Technology, the digital economy of 47 economies accounted for 45% of GDP in 2021, which shows that the digital economy is in the ascendant.

The impact of the digital economy on income is dialectical. In different national conditions and policy contexts, the digital economy interacts with related scientific, technological, political and cultural forces, and whether income inequality can be alleviated depends on the outcome of their game[3]. From the perspective of "digital dividend", the digital economy has great advantages in saving economic costs including search, copying, transportation, tracking and verification costs[4], and the popularization of the Internet and information and communication technology can optimize the allocation of resources and improve the speed of information circulation, thereby strengthening education investment, transforming industrial structure, and promoting economic development[5]. Flexible and timely online job search can break the shackles of traditional local employment processes on workers, and the more workers choose to sign online employment contracts[6], the digital economy can provide jobs and increase employability, and accommodate more workers. In contrast, the "digital divide" will make economic development face the dilemma of information asymmetry, higher digital employment threshold, and skills bias, and information flood and data monopoly will also exacerbate income inequality[7].

Due to complex impact mechanisms and changing research perspectives, the relationship between digital economy and income inequality has not yet been unified in academia. Positive academics believe that the digital economy can increase income while reducing income inequality. Scholars with different views associate the digital economy with rising income inequality. Many scholars have examined the relationship between the digital economy and income inequality from multiple perspectives. At the national level, digital technologies can contribute to poverty reduction in Arab countries[8]; Internet penetration has alleviated poverty in rural Mexico more than in urban areas [9]. The use of ICTs has enabled Indonesia's fintech and e-commerce to digitize and reduce inequality through income-increasing poverty reduction and employment [10]. In terms of gender income,

the digital economy can reduce gender income inequality by helping female workers expand their social networks and increase their income from switching jobs, which is more positive than that of men[11]; In terms of employment income, the relationship between artificial intelligence and workers affects the wage level and income share of labor, and then has different impacts on income distribution[12]; In terms of regional income, the digital economy has a spatial spillover effect and can promote regional economic development[13], but the promotion of digital infrastructure and the Internet will widen the income gap between urban and rural areas in the region[14]. From a cross-border perspective, countries in the Asia-Pacific region, especially middle-income countries and above, can reduce income disparities by vigorously developing the digital economy[15]. The digital economy has led to technological advances, increased access to education, increased labor force employment, and financial inclusion, reducing global income inequality[16]. However, the consumption problems of low-income groups caused by digitalization and financialization will widen the income gap to a certain extent[17]; In winner-take-all market structures, especially for high-income groups in OECD countries, digital innovation can exacerbate income inequality [18].

Income inequality has a long history of research in academia, and the recent boom in the digital economy has been exhausted. The research on digital economy mainly focuses on the meaning and characteristics of digital economy, accounting and analysis, the relationship between digital economy and economic development, and governance policies. Research on income inequality revolves around the relationship between economic growth and income inequality, the causes and effects of income inequality, heterogeneity in different countries and stages of development, and policy recommendations.

Through literature review, it can be found that the current research on digital economy and income inequality is mainly from the perspective of functional income distribution and large-scale income distribution. In terms of functional income distribution, research has been carried out on the analysis of labor relations, the definition of data elements and their ownership, and the promotion of industrial upgrading by digital technology. In terms of large-scale income distribution, scholars have explored the income gap within and between different groups, such as the urban-rural income gap, the gender income gap, and the income gap between workers with different skills. In terms of influence mechanism, the research mainly focuses on the role of human capital, employment quality, digital finance, scientific and technological progress and other mechanisms in the relationship between digital economy and income inequality.

On the whole, few studies have empirically analyzed the digital economy, industrial structure and income distribution from a global perspective. Therefore, this paper uses cross-border panel data from 49 countries from 2010 to 2020 to study the impact of the digital economy on income inequality. Compared with the existing literature, the marginal contribution of this paper is as follows: First, it breaks out of the sample limitation of focusing on one country for research, and selects 49 countries from the global level for empirical analysis, and the results are of universal significance. Second, the upgrading of industrial structure is included in the analysis framework, and the relationship between digital economy and income inequality is explored from the perspectives of advanced industrial structure and rationalization of industrial structure, so as to enrich existing research.

2. Literature Review and Theoretical Analysis

As an emerging technological economic paradigm, the digital economy introduces digital information and knowledge different from traditional production factors through scientific and technological innovation, realizes efficient connection and accurate matching of all participants, deepens the industrial revolution and technological revolution on the basis of taking root in the modern information network platform, and new formats and new models emerge one after another. There is no doubt that in the process of changing all aspects of society in the digital economy, and in the process of deep integration of digital technology and the real economy, digital industrialization and industrial digitalization have driven the upgrading of industrial structure [19]. As one of the important factors affecting income distribution, the change of industrial structure is related to the development speed of various industries and the ratio of production resources [20]. Therefore, this paper argues that industrial structure upgrading is an important mechanism for reducing income inequality in the digital economy[21].

On the one hand, the digital economy has spawned many new industries. As the basic support, the Internet, big data, artificial intelligence and other emerging technologies have been transformed into economic development power, digital applications have brought products and services that have not been available before, and the information and communication industry, electronic manufacturing, software development industry and so on have profoundly changed the traditional industrial structure. On the other hand, the digital economy has accelerated the integration of traditional industries and emerging industries and promoted the application of digital technology among traditional industries [22]. The technology penetration of the digital economy into various industries has industrial heterogeneity, and for the relatively lagging primary industry, the superposition of digital technology clearly shows the role of improving production efficiency and collaboration efficiency in the secondary and tertiary industries [23]. In particular, the achievements of scientific and technological innovation are transformed into the improvement of labor productivity in the tertiary industry, and the overall structure of the industry is developing in the direction of servitization and advanced, so as to realize the upgrading of industrial structure [24].

The mechanisms of the digital economy affecting the industrial structure mainly include: First, labor skill preferences. Labor skill structure optimization, that is, the increase in the proportion of high-skilled labor, is an important channel for the digital economy to promote industrial structure upgrading [25]. As a result of equalization of education and reduced costs of access to information, groups with difficulty in education have the opportunity to improve their human capital more easily and quickly [26]; At the same time, in order to adapt to the employment mode and production mode in the digital economy era, workers continue to use the Internet and information and communication technology to improve labor skills [27].In short, the digital economy has promoted the transformation of simple repetitive skilled workers into medium- and high-skilled workers, and achieved the optimal allocation of labor resources. The increase in the intellectual labor force will

promote the adjustment of the proportion between and within industries, with the share of labor-intensive industries decreasing and the share of knowledge-intensive and skill-intensive industries increasing. The second is the consumption structure. The change of consumption structure affects the upgrading of industrial structure, and the digital economy drives the advanced and rationalization of industrial structure through the effect of demand consumption [28]. The digital economy provides countless products and services for the public, and consumers naturally increase their demand for personalized and accurate matching of products and services, which is reflected in the production field is the improvement model of enterprises, updating technology and research and development of new products, and the proportion of secondary and tertiary industries in the total economy. Consumption modes such as logistics express, platform live broadcast, and e-commerce break the boundaries of time and space, urban and rural boundaries, offline consumption is transformed into online consumption, and the market economy automatically stimulates the upgrading of production structure according to the transformation of consumption patterns [29]. The third is digital infrastructure. Compared with the traditional infrastructure that relies on manufacturing, digital infrastructure such as artificial intelligence, Internet of Things, and the Internet is more inclined to the service industry and financial industry in terms of production input because the source of science and technology is a new generation of communication technology. The combination of capital and digital gives digital infrastructure broad versatility and flexible penetration, and automation technology saves labor in the production process, thereby increasing the proportion of output value of capital-intensive industries [30].

The digital economy has promoted the upgrading of industrial structure through high-skilled labor preferences, demand consumption upgrades, and accelerated digital infrastructure construction, which not only narrows the income gap between urban and rural areas, but also further alleviates income inequality from the aspects of promoting the flow of production resources and improving employment.

First, while narrowing the income gap between urban and rural areas, while the digital economy promotes the upgrading of industrial structure, technology spillover and information flow will also provide opportunities for rural workers to increase their income. The popularization of information and communication technology and the Internet has enabled the labor force to flow from low-income primary industries to relatively high-income secondary and tertiary industries with the upgrading of industrial structure. The secondary and tertiary industries are mainly developed in urban areas, with the characteristics of high technology, high efficiency and high welfare, while the primary industry is concentrated in rural areas, with low productivity and slow development. The increase in labor supply not only lowers the wages of high-skilled workers such as urban management and R&D personnel, but also increases the income of rural workers [31]; With the advancement of the new urbanization process relying on the upgrading of industrial structure, a large number of surplus labor in rural areas has been absorbed by the rapidly increasing labor demand in cities, and the yield of land has continued to increase, which has also narrowed the income gap between urban and rural areas to a certain extent [32]. At the same time, the deep integration of digital technology and agriculture has realized the advanced, intelligent and professional agricultural production methods, promoted the upgrading of the primary industry to digital technology services, and finally profoundly changed rural production and life with economies of scale and external spillover effects [33].

Secondly, in terms of the flow of production resources, digital technology, as the engine of development, provides assistance for the cross-integration of the three industries and the upgrading of the industrial chain, and the upgrading of production resources in line with the industrial structure gradually realizes cross-industry and cross-regional flow, which can alleviate the income inequality of different industries and regions. In other words, changes in industrial structure will affect income patterns through changes in production factors [34]. The digital economy improves the degree of industrial sophistication from the qualitative and quantitative aspects, so that production resources are rationally allocated and freely flowing between all links of production [35], and data elements and traditional production materials are effectively matched through the reconciliation of digital technology, which not only improves the skill level and employment adaptability of workers, but also increases the application of labor tools, expands the scope of use of labor objects, fully breaks the temporal and spatial constraints of traditional production factors [36], and improves the possibility of low-income people using limited resources to obtain more income.

Finally, in terms of improving employment, the digital economy has given the characteristics of digitalization and intelligence to the industrial structure, and technological progress has changed the employment structure and employment quality [37], which provides a new way to improve income inequality. The digital economy optimizes the proportion and coordination of primary, secondary and tertiary industries in the overall industrial layout, thereby changing the requirements for workers' skills. In the short term, the spread of digital technology across industries will not only increase the demand for high-skilled workers, but also use artificial intelligence to replace simple work, both of which will reduce the number of low-skilled workers[38]; In the long run, low-skilled workers will continue to learn knowledge and skills in the digital age through the Internet, big data and other tools under pressure to survive or for the purpose of improving employment competitiveness [39], and the Internet and education and training have increased women's employment opportunities, changed women's weak position in employment[40], increased the salary of low-income groups while alleviating income inequality between different categories of workers.

3. Research Design

3.1. Sample selection and data sources

This paper studies the impact of the digital economy on income inequality based on cross-border panel data from 49 countries from 2010 to 2020. The data are mainly from the World Bank database (WDI), the standardized World Income Inequality Database database (SWIID), and the World Income Inequality Database (WIID).

3.1.1. Variable to be explained: Gini coefficient.

The Gini coefficient describes the degree to which the real income distribution within an economy deviates from the distribution of full equality. A Gini coefficient of 0 indicates complete equality, and a value of 1 indicates complete

inequality. As a widely used measure of income inequality, the Gini coefficient is undoubtedly the most authoritative and recognized indicator. Due to the different measurement standards from country to country, the Gini coefficient lacks comparability in terms of cross-country comparisons. Based on the World Income Inequality Database (WIID), maintained by the United Nations University-World Institute for Development Economics Research (UNU-WIDER), which contains data information on inequality in various countries, Frederick (2021) uses the Luxembourg Income Research Database (LIS) as a benchmark, incorporates information from OECD, World Bank and other databases, and establishes a standardized World Income Inequality Database (SWIID) through the standardization of WIID data. It includes a comparable Gini coefficient for 198 countries in the world after 1960, adding comparability and breadth to cross-country studies of income inequality. In this paper, the Gini coefficient in the WAID database is used for benchmark regression, and the net value of the Gini coefficient and the market value of the Gini coefficient in the SWIID database are used to verify the robustness.

3.1.2. Explanatory variables: the digital economy.

With the development of the definition of the digital economy, the measurement of the digital economy has also been enriched. The difference in emphasis, observation angle, and system construction means that the measurement of the digital economy is diverse. At present, many scholars and institutions mainly use the principle of value-added accounting and the establishment of digital economy index system to measure the scale of digital economy development [41]. For example, the ICT Development Index (IDI) published by the International Telecommunication Union (ITU) from 2007 to 2017 (missing 2009 data) focuses on the observation of ICT, while the United Nations E-Government Development Index (EDGI) published every two years since 2003. Therefore, this paper draws on the research of existing scholars to measure the development level of digital economy from the relevant indicators of digital infrastructure, digital industry development and digital scientific research and innovation. The measurement system is shown in Table 1.

Table 1. Digital economy indicator measurement system

Level 1 indicators	Level 2 indicators	Level 3 indicators	Nature of indicators
Digital Industry	Digital Infrastructure	Landline subscribers (per 100 people)	Positive
		Mobile subscriptions (per 100 people)	Positive
		Fixed broadband subscription (per 100 people)	Positive
		Internet penetration rate (%)	Positive
	Digital Industry Development	ICT Product Exports/Total Product Exports(%)	Positive
		ICT Services Exports/Total Services Exports (%)	Positive
		Communications Computer Transactions / Service Exports (%)	Positive
		Communications Computer Transactions / Imports of Services (%)	Positive
		Telecommunications High-tech Exports/ Manufacturing Exports (%)	Positive
		Communication High-tech Manufacturing Value-added / Manufacturing Value-added (%)	Positive
	Digital research innovation	Science and technology journal articles positive	Positive
		Intellectual property royalties are forward	Positive

Drawing on the practice of Liu Jun et al. (2020) [42], the original tertiary indicators with large numerical differences and non-uniform measurement units are first dimensionalized. The processing formula is as follows:

$$X'_{n,t} = \frac{X_{n,t} - \min X_{n,2010}}{\max X_{n,2010} - \min X_{n,2010}} \times 100$$

Among them, X represents a third-level indicator of the digital economy, t represents a certain t period, and n represents the nth country. $\min X_{n,2010}$ and $\max X_{n,2010}$ represent the minimum and maximum values of an indicator X of the digital economy with 2010 as the base period. $X'_{n,j}$ represents a three-level indicator of the digital economy that is comparable at both the time dimension and the country level.

After standardization, the equal-weight assignment method is used for linear weighting, and finally the digital economy index (DEI) is obtained.

$$dei_{n,t} = \sum_{j=1}^{12} w_j X'_{n,t}$$

Among them, the w_j is the reciprocal of the number of third-level indicators, representing the weight of the jth third-level indicator.

3.1.3. Intermediary variables:

Industrial structure upgrading refers to the transformation of industrial structure to the direction of servitization, from a low-level level to a high-level level, which is manifested in the advanced industrial structure and the rationalization of the industrial structure [43].

Advanced Industrial Structure Index (TS): Advanced industrial structure refers to the gradual transfer of the advantages of the primary industry to the secondary and tertiary industries; The advantages of labor-intensive industries are gradually transferred to capital, technology and knowledge-intensive industries; Primary manufacturing advantages shift to advanced manufacturing [44]. This paper draws on the measurement method of Yuan Hang and Zhu Cheng liang (2018) [45] and uses the following formula:

$$TS=\sum_{i=1}^{3}(i*y_{n,i,t})$$

Among them, i represents the ith industry, n represents the nth country, t represents a certain t period, and y represents the proportion of industrial output value to GDP.

TS index is a positive index, the value is between 1 and 3, the smaller the value indicates the lower the level of industrial structure development, the larger indicates the higher the level of industrial structure development.

Industrial Structure Rationalization Index (TL): Industrial structure rationalization refers to optimizing the organic connection between industries

Department and collaboration ability, reflecting the efficiency of resource allocation between industries and the improvement of aggregation quality [46]. Drawing on the research of Gan Chunhui et al. (2011) [47], the specific formula is as follows:

$$TL=\sum_{i=1}^{3} ln\left(\frac{Y_{n,i,t}*L_{n,i}}{Y_{n,i}*L_{n,i,t}}\right)*\left(Y_{n,i,t}/Y_{n,i}\right)$$

where Y represents the output value and L represents the number of employed people.

The TL index is an inverse indicator, the closer its absolute value is to 0, the more reasonable the industrial structure, the larger the absolute value, the more unreasonable the industrial structure.

3.1.4. Control variables:

(1) level of economic development (LNGDP): per capita GDP logarithmic;

(2) Government expenditure (gov): government expenditure as a percentage of GDP;

(3) inflation rate (infla);

(4) population growth rate (popular);

(5) years of primary education (EDU);

(6) Openness: the proportion of total imports and exports to GDP;

(7) unemployment rate (unemploy);

(8) Urbanization rate (urban).

The descriptive statistics of the relevant variables are shown in Table 2.

Table 2. Descriptive statistics for major variables

Variable	Sample Size	Mean	Standard Deviation	Minimum	Maximum
Gini_disp	539	34.73	7.334	22.30	50.90
Gini_mkt	539	46.86	5.231	32.60	57.60
Gini	539	35.98	8.101	22.50	54.61
dei	539	40.45	15.32	10.64	79.85
TS	539	2.354	0.136	1.876	2.704
TL	539	2.060	0.828	0.005	3.796
lngdp	539	11.47	2.167	7.494	17.89
infla	539	4.270	7.340	-4.621	75.28
popular	539	0.530	0.794	-2.258	2.431
urban	539	71.32	13.31	42.49	95.51
open	539	88.28	51.59	22.49	377.8
edu	539	5.417	0.910	4	7
unemploy	539	7.423	4.855	0.250	33.13
gov	539	17.56	4.095	8.321	27.37

3.2. Model design

This paper constructs the following econometric model to study the impact of digital economy on income inequality:

$$\mathrm{Gini}_{n,t}=a_0+a_1\mathrm{dei}_{n,t}+\sum_{k=1}^{8}a_k\mathrm{Control}_{n,t}+\mu_n+\lambda_t+\varepsilon_{n,t}$$

where n represents the country and t represents the time. The explanatory variables $\mathrm{Gini}_{n,t}$ represent the Gini coefficient of the t year of n countries, and the core explanatory variable $\mathrm{dei}_{n,t}$ represents the digital economy level of the t year of n countries, and a_0、a_1、a_k are the estimated coefficients. $\mathrm{Control}_{n,t}$ represents each control variable, μ_n is the national fixed effect, λ_t is the year fixed effect, and $\varepsilon_{n,t}$ is the random perturbation term.

4. Empirical Research

4.1. Benchmark regression

This paper first examines the impact of the digital economy on income inequality at the whole sample level, selects a fixed-effect model through the Hausman test, and controls for national and annual fixed effects. The results are shown in Table 3: in the regression, column (1) does not introduce control variables, column (2) increases control variables such as GDP per capita, government expenditure, inflation rate, population growth rate, years of primary education, trade openness, unemployment rate, urbanization rate, etc., and column (3) only controls for national fixed effects. It can be observed that the impact of the digital economy on the Gini coefficient is significantly negative at the level of 1%, indicating that the development of the digital economy can help alleviate income inequality.

4.2. Robustness test

Replace the explanatory variables: replace the Gini coefficient (Gini) in the WAID database with the net Gini coefficient (Gini_disp) and the Gini coefficient market value (Gini_mkt) in the SWIID database, and the regression results are shown in the model (1) and (2) in Table 4: whether the net Gini coefficient (Gini_disp) or the Gini coefficient market value (Gini_mkt) of the interpreted variable, the coefficient between the digital economy and income inequality is still significantly negative at the level of 1%. The negative effect between the two is stable.

Tail shrinking treatment: In order to eliminate the influence of outliers of each variable on the regression results, this paper uses a two-way fixed-effect model regression after 1% tail reduction treatment of variables, and the regression results are shown in the model (3) in Table 4: After tail reduction, the

reverse influence of the digital economy on the Gini coefficient is significant at the level of 1%. The robustness test shows that the benchmark regression results are reliable.

Table 3. Benchmark model

	FE	FE	FE
	(1)	(2)	(3)
Variable	Gini	Gini	Gini
dei	-0.114***	-0.110***	-0.095***
	(-3.35)	(-2.96)	(-3.00)
lngdp		-0.198	-0.419
		(-0.42)	(-1.03)
infla		0.015	0.019
		(0.89)	(1.15)
popular		0.161	0.135
		(0.58)	(0.50)
urban		-0.003	-0.030
		(-0.03)	(-0.37)
open		0.011	0.007
		(1.12)	(0.79)
edu		0.940	0.837
		(1.48)	(1.34)
unemploy		0.127***	0.125***
		(3.10)	(3.28)
gov		0.058	0.102
		(0.63)	(1.22)
Constant	40.915***	35.022***	38.727***
	(32.25)	(3.74)	(5.63)
Observations	539	539	539
R-squared	0.089	0.121	0.115
country FE	YES	YES	YES
year FE	YES	YES	NO

Note: T values are in parentheses. ***, **, and * represent significance at significance levels of 1%, 5%, and 10%, respectively. Same below.

Table 4. Robustness test

	(1)	(2)	(3)
Variable	Gini_disp	Gini_mkt	Gini
dei	-0.096***	-0.084***	-0.121***
	(-5.11)	(-4.59)	(-3.10)
lngdp	-0.072	-0.407*	-0.050
	(-0.30)	(-1.73)	(-0.10)
infla	-0.002	-0.003	0.028
	(-0.27)	(-0.35)	(1.21)
popular	0.104	-0.114	0.014
	(0.75)	(-0.83)	(0.05)
urban	0.077*	0.121***	0.004
	(1.65)	(2.64)	(0.05)
open	0.018***	0.018***	0.006
	(3.80)	(3.94)	(0.55)
edu	0.913***	0.624**	0.983
	(2.85)	(1.98)	(1.55)
unemploy	0.050**	0.068***	0.083**
	(2.44)	(3.38)	(1.99)
gov	-0.117**	-0.124***	0.088
	(-2.51)	(-2.71)	(0.96)
Constant	29.410***	43.254***	33.222***
	(6.24)	(9.34)	(3.43)
Observations	539	539	539
R-squared	0.246	0.223	0.112
country FE	YES	YES	YES
year FE	YES	YES	YES

4.3. Endogeneity

Although the factors that have an impact on income inequality are included as control variables as much as possible in the benchmark regression, there are inevitably missing variables in the model, resulting in errors in the regression analysis to test the impact of the digital economy on income inequality. And there is a reverse causal relationship between the development of the digital economy

and income inequality. On the one hand, countries with high income inequality have more high-income groups, and high-income earners are also high-income investors who can invest a lot of money in digital technology innovation; On the other hand, countries with small income gaps have a stable social environment, which is conducive to the construction of digital infrastructure and the promotion of digital education. In the absence of suitable instrumental variables, this paper uses the digital economic indicator with a lag period as the instrumental variable, and uses the two-stage least squares method (2SLS) and the two-step generalized moment estimation (2S-GMM) for endogenous processing. The endogenous test results are shown in Table 5: The coefficients of the digital economy are significantly negative with or without the addition of control variables.

Table 5. Endogenous tests

	2SLS	2SLS	2S-GMM	2S-GMM
Variable	Gini	Gini	Gini	Gini
dei	-0.113***	-0.121**	-0.113***	-0.121**
	(-2.59)	(-2.47)	(-2.59)	(-2.47)
Control variables	No	Yes	No	Yes
Constant	46.069***	38.081***	46.069***	38.081***
	(22.88)	(3.18)	(22.88)	(3.18)
Observations	490	489	490	489
R-squared	0.967	0.968	0.967	0.968
country FE	YES	YES	YES	YES
year FE	YES	YES	YES	YES
Cragg-Donald Wald F	3689.42 { 16.8}	546.119 { 16.38}	3689.42 { 16.8}	546.119 { 16.38}
Kleibergen-Paap rk Wald F	239.591 { 16.38}	191.858 { 16.38}	239.591 { 16.38}	191.858 { 16.38}
Kleibergen-Paap rk LM	46.161 [＜0.01]	68.344 [＜0.01]	46.161 [＜0.01]	68.344 [＜0.01]

Note: {} is the critical value of the Stock-Yogo weak instrumental variable test 10% level, and the p value in [] is less than 0.01.

4.4. Mediation effect

Refer to Jiang ting (2022) [48] Set the mediation effect model as follows for step-by-step testing:

$$\mathrm{Gini}_{n,t} = a_0 + a_1 \mathrm{dei}_{n,t} + \sum_{k=1}^{8} a_k \mathrm{Control}_{n,t} + \mu_n + \lambda_t + \varepsilon_{n,t}$$

$$\mathrm{Med}_{n,t} = \beta_0 + \beta_1 \mathrm{dei}_{n,t} + \sum_{k=1}^{8} \beta_k \mathrm{Control}_{n,t} + \mu_n + \lambda_t + \varepsilon_{n,t}$$

$$\mathrm{Gini}_{n,t} = \gamma_0 + \gamma_1 \mathrm{dei}_{n,t} + \gamma_2 \mathrm{Med}_{n,t} + \sum_{k=1}^{8} \gamma_k \mathrm{Control}_{n,t} + \mu_n + \lambda_t + \varepsilon_{n,t}$$

In the above three formulas, Med_ (n,t) represents the intermediary variables, namely the industrial structure advanced index (TS) and the industrial structure rationalization index (TL); Control_(n,t) represents each control variable, and a, β, and γ are the influence coefficients. The mediation effect test requires that the total utility a_1, the effect of the independent variable on the mediation variable_1 β, the effect of the mediation variable on the mediation variable γ_2 is not zero, and the direct effect γ_1 is zero or its absolute value is less than a_1.

The results of the mediation effect test are shown in Table 6: Columns (1) and (2) verify the mechanism role of the industrial structure rationalization index (TL) in the process of digital economy affecting income inequality. In column (1), the impact of the digital economy on the rationalization of industrial structure is significantly negative at the 5% level, indicating that the digital economy promotes the optimization of industrial structure; In column (2), the digital economy reduces income inequality by a significant level of 1%, which means that the digital economy can achieve a reduction in income inequality by improving the ability of inter-industry collaboration and aggregation. Columns (3) and (4) verify the relationship between advanced industrial structure, digital economy, and income inequality. Column (3) indicates the digital economy

The advanced industrial structure is promoted at a significant level of 1%, and the coefficients of advanced industrial structure and digital economy on income inequality in column (4) are both negative at a significant level of 1%, and the digital economy promotes the transformation of low-level industries to high-level industries, thereby alleviating income inequality.

4.5. Testing for heterogeneity

This paper uses quantile regression to analyze the impact of digital economy on income inequality at different quantiles. The test results are shown in Table 7: At different quantiles of income inequality, the impact of the digital economy on income inequality is significantly negative. When the income inequality quantile point exceeds the 50th percentile, the mitigating effect of the digital economy on income inequality is higher. When the income inequality quantile is 90 percentile, the coefficient of influence of the digital economy on income inequality is -0.016, which is the smallest absolute value. That is, the groups of countries with the greatest levels of income inequality are the least positively affected by the digital economy. This may be because economies with weak economic development and low income levels are easily excluded from the development of the digital economy, which in turn falls into the quagmire of economic and income stagnation; Of course, social unrest and economic disorder caused by excessive income inequality are more likely to miss

the development opportunities of the digital economy.

Table 6. Mediation effect test

	(1)	(2)	(3)	(4)
	TL	Gini	TS	Gini
dei	-0.001**	-0.103***	0.002***	-0.096**
	(-1.99)	(-2.77)	(3.19)	(-2.57)
TL		7.968**		
		(1.97)		
TS				-7.083**
				(-2.53)
lngdp	0.049***	-0.591	-0.001	-0.204
	(9.11)	(-1.15)	(-0.11)	(-0.43)
infla	0.000**	0.011	-0.000	0.014
	(2.30)	(0.68)	(-0.53)	(0.83)
popular	0.011***	0.070	-0.001	0.156
	(3.62)	(0.25)	(-0.15)	(0.57)
urban	0.005***	-0.040	0.002	0.012
	(4.41)	(-0.43)	(1.43)	(0.13)
open	0.000***	0.008	-0.000*	0.009
	(3.03)	(0.84)	(-1.91)	(0.90)
edu	-0.006	0.989	0.027**	1.130*
	(-0.85)	(1.56)	(2.56)	(1.77)
unemploy	0.001	0.121***	-0.000	0.124***
	(1.49)	(2.97)	(-0.52)	(3.06)
gov	0.000	0.058	0.014***	0.154
	(0.05)	(0.63)	(8.93)	(1.55)
Constant	-0.783***	41.264***	1.780***	47.633***
	(-7.35)	(4.18)	(11.58)	(4.51)
Observations	538	538	538	538
R-squared	0.296	0.128	0.321	0.133
country FE	YES	YES	YES	YES
year FE	YES	YES	YES	YES

Table 7. Heterogeneity test

	10 Quantiles	25 Quantiles	50 Quantiles	75 Quantiles	90 Quantiles
	Gini	Gini	Gini	Gini	Gini
dei	-0.115***	-0.114***	-0.134***	-0.137***	-0.016***
	(-224.52)	(-497.40)	(-150.51)	(-36.09)	(-4.45)
lngdp	-0.665***	-0.373***	0.133***	0.377***	-0.119***
	(-196.38)	(-146.32)	(49.21)	(5.68)	(-4.92)
infla	-0.253***	-0.134***	-0.098***	-0.096***	-0.110***
	(-565.92)	(-276.15)	(-85.15)	(-2.79)	(-16.39)
popular	-0.342***	2.199***	2.763***	2.913***	2.117***
	(-27.92)	(550.72)	(216.56)	(16.81)	(9.23)
urban	0.114***	0.117***	0.078***	0.079***	0.128***
	(159.44)	(860.25)	(73.23)	(3.55)	(19.54)
open	-0.058***	-0.052***	-0.053***	-0.040***	-0.066***
	(-378.52)	(-1,191.85)	(-590.86)	(-6.89)	(-53.39)
edu	2.363***	-0.236***	-0.480***	0.069	0.723***
	(109.61)	(-73.31)	(-72.24)	(0.63)	(13.45)
unemploy	0.244***	0.188***	0.172***	0.128***	0.257***
	(37.63)	(274.67)	(56.04)	(5.01)	(36.51)
gov	-0.840***	-0.804***	-1.027***	-0.887***	-1.553***
	(-143.66)	(-953.53)	(-404.03)	(-42.19)	(-109.51)
country FE	YES	YES	YES	YES	YES
year FE	YES	YES	YES	YES	YES

5. Conclusion

Based on the cross-border panel data of 49 countries from 2010 to 2020, this paper studies the impact of digital economy development on income inequality from both institutional and empirical levels. It is found that: First, the development of the digital economy significantly reduces income inequality, and the conclusion is still valid after replacing the explanatory variables, shrinking the tail treatment and eliminating endogeneity. Second, the digital economy indirectly alleviates income inequality and narrows income disparity by promoting the advanced and rational industrial structure. Third, the mitigating effect of the digital economy in countries with high income inequality is more pronounced than in countries with low income inequality, but when countries fall into extreme income inequality, the digital economy has little effect on reducing income inequality.

Based on the above research conclusions, this paper puts forward the following policy recommendations: first, seize the development opportunities in the digital economy era and

promote digital technology innovation and digital infrastructure construction; At the same time, we will accelerate the resolution of the negative impact of the digital divide, reduce the inequality in digital access and digital use, increase the participation of all groups in the digital economy, benefit all people with digital dividends, and guide the digital economy to play a positive role in reducing income inequality. Second, pay attention to the positive effect of industrial structure upgrading on income inequality. Through scientific and technological innovation, we will steadily improve the aggregation capacity of the three industries, and give full play to the role of industrial digitalization and digital industrialization in empowering the transformation and upgrading of real industries. Third, to break the vicious circle of income inequality and low activity of the digital economy, the government needs to vigorously promote the free flow of digital resources while maintaining the overall income gap at an appropriate level through the reform of the income distribution system.

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