Research on regional digitalization effect and its influencing factors in China from the perspective of firm heterogeneity

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Abstract: At present, digital transformation has become an important engine to promote China's economic growth under the new development pattern. However, unbalanced development has caused the problem of digital divide, which limits the healthy and sustainable development of economy and society. Based on China's inter-regional input-output model that distinguishes enterprise heterogeneity, this paper constructs a digital accounting framework to quantitatively analyze the characteristic differences of the digital level of enterprises in different regions, industries and ownership in China, explore the "digital divide" problem generated in the process of China's digital development, and further analyze the main driving factors in the process. It is found that there is a distinct regional digital divide phenomenon in China, with the digitalization level in the eastern region being higher than that in other regions. There are also significant differences in digitalization levels among different types of enterprises. The digitalization level of foreign-funded enterprises (especially those from Hong Kong, Macao and Taiwan regions of China) is significantly higher than that of domestic firms. Foreign capital is accelerating the digital transformation of traditional manufacturing and modern service industries in China's central and western regions, constantly narrowing the gap with the southeast coastal areas, and promote the deepening of domestic value chain division of labor. Furthermore, the results show that the joint production between foreign capital and domestic firms is gradually playing a positive role, creating new development space for China's digital transformation. It is necessary to strengthen digital technology cooperation with foreign-funded enterprises to lead the digital transformation and development of the domestic industrial chain.

Keywords: Digitalization; Regional digital divide; Enterprise digital divide; Influencing factors

1 Introduction

With the advancement of the new round of technological revolution, human society has entered the era of digital economy. Digital technologies such as Internet technology, artificial intelligence, robotics, and cloud computing are developing rapidly and gradually penetrating into all fields of the economy and society, promoting significant changes in the production and transaction models. The scale of the digital economy continues to expand and is increasingly becoming a new driving force for China's economic growth. China attaches great importance to the development of the digital economy. President Xi has emphasized promoting the construction of "Digital China" and

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promoting "the deep integration of the Internet, big data, artificial intelligence and the real economy". Since the 18th National Congress of the Communist Party of China, China's digital economy has entered an accelerated development cycle, with its scale steadily increasing. In 2023, it expanded to 53.9 trillion-yuan, accounting for as high as 42.8% of the GDP. Among them, industrial digitalization has gradually taken the important position in the digital economy. Digital transformation has entered a new stage of integrated development with the real economy. Traditional industries are accelerating their transformation towards digitalization, networking and intelligence, becoming an important engine driving China's economic growth under the new development pattern

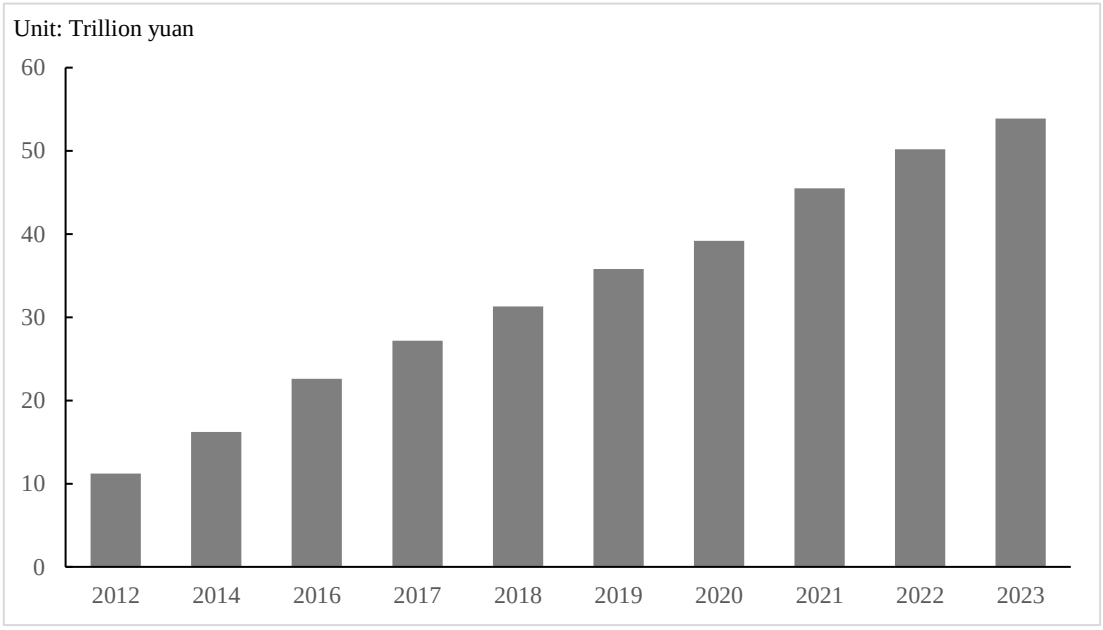

Figure 1. The scale of China's digital economy from 2012 to 2023

Source: China Academy of Information and Communications Technology.

However, during the development of digitalization in China, an unbalanced situation has emerged, resulting in the problem of the digital divide. Due to the obvious regional and group heterogeneity in the development of the Internet, certain differences have emerged among different groups in their production and life processes. As a result, there are significant disparities in the development of China's digital economy among provinces (Zhang et al., 2017), among enterprises (Wang et al., 2022), and among groups (He et al., 2020). In 2013, the "Research on the Digital Divide in China" released by the National Information Center of China defined the digital divide as "the gap existing among different social groups in terms of possessing and using modern information technology". The existence of the digital divide has isolated some groups from the achievements of the digital economy, preventing them from fairly enjoying the social dividends brought by digital technologies. This has further restricted the healthy and sustainable development of the economy and society, becoming a key issue restricting the construction of Digital China (Kong et al., 2021; Duan et al., 2024). For example, the emergence of the digital divide between urban and rural areas may widen the income gap (Liu and Yu, 2023), becoming an unstable factor for social development; and many enterprises or industries are experiencing severe "fragmentation" or "isolation" due to the "emphasis on internal and neglect of external" during the process of digital transformation, which makes it difficult for the spillover and external effects of the digital economy to be manifested. Therefore,

measuring the development of China's digitalization and its differences among various regions and groups is of vital importance for researchers and policymakers to understand and predict the development of China's economy.

Although a large number of studies have been carried out on the scale and degree of digitalization, there is no uniformity either in terms of measurement methods or defined scope. Before the concept of the digital economy was proposed, Mark Porat put forward the measurement method of the information economy as early as 1977, dividing the primary information and secondary information sectors and using the value-added method for scale measurement (Porat, 1977). In 1996, Tapscott (1996) proposed the concept of the digital economy, and some international institutions and organizations began to define and measure it. The Bureau of Economic Analysis (BEA) of the United States has defined the digital economy from three aspects: digital infrastructure, digital trading systems, and digital content, and has measured the scale of the value added and total output of the digital economy in the United States. OECD (2014) proposed a measurement framework for the digital economy and constructed a statistical indicator system for ICT and the digital economy. Although the China Academy of Information and Communications Technology (2019), Xu and Zhang (2020), and Cai and Niu (2021) all provided digital measurement methods, they are different in terms of the digital industry scope, the accounting framework, and the construction of indicators. Furthermore, in previous studies, due to the availability of data and the practicality of methods, most have characterized the degree of digital transformation of specific economic activity subjects from the overall digital economy impact. To a certain extent, not only have the technical and economic connections among different countries and industries been ignored, Moreover, it is difficult to capture the direct and indirect impacts brought about by the use of digital technologies. Therefore, this paper measures the level of digitalization based on input-output data. Besides the accessibility of the data, more importantly, the IO method allows for the capture of the direct and indirect impacts caused by the use of digital technologies by considering production interactions across industries and countries.

Based on clearly defining the scope of the digital economy, this paper constructs a digital accounting framework based on the multi-regional input-output model, and defines digitalization indicators from the perspective of backward industrial correlation to quantify the digitalization level at the regional-industry-enterprise level in China, and explores the problems of "regional digital divide" and "enterprise digital divide" arising in the process of China's digital development. And further analyze the driving factors of the changes in China's digitalization level. Finally, explore the impact of digitalization on the domestic value chain and its potential mechanisms. The major contributions are as follows: (1) By dividing the content of embedded factors into digital activities and non-digital activities, a unified digital accounting framework is constructed at the production level, and China's digital level index is defined from the perspective of backward industrial correlation to supplement the research on China's domestic and cross-border digital accounting; (2) Add enterprise ownership information on the basis of region-industry level, measure the current situation and development trend of China's digitalization scale and digitalization level from three dimensions of region-enterprise-industry, and discuss the "regional digital divide" and "enterprise digital divide" generated in the process of China's digitalization development; (3) The structure decomposition method is adopted to conduct an in-depth analysis of the factors affecting the change of China's digitalization level, focusing on identifying the key driving forces promoting the growth of China's

digitalization level, and interpreting the role of Hong Kong, Macao and Taiwan regions of China invested enterprises and other foreign invested enterprises in the differentiated development of digitalization level in China's provinces.

The remainder of the paper is organized as follows: section 2 introduces the scope of the digital economy and the digital accounting framework based on the multi-regional input-output model. Sections 3 and 4 present the basic results. Section 3 analyzes the characteristic and changing trends of China's digitalization level from the regional, enterprise and industry level. Section 4 examines the driving factors of the changes in China's digitalization level during different time periods. Section 5 further explores the potential relationship between digitalization level and the division of labor in the domestic value chain, revealing the impact effect and potential mechanism of digitalization on the domestic value chain. Section 6 concludes.

2 Methodology and data

2.1 The definition and scope of digitalization

The gap in information resources and the skills of using information technology are the direct causes of the digital divide, and the two play roles respectively in terms of "information possession" and "information usage". From a certain perspective, it refers to the digital industrialization effect and the industrial digitalization effect. In 2017, the China Academy of Information and Communications Technology first provided the classification standards for the "digital industrialization" and "industrial digitalization"[1]. The former refers to the products or services directly provided by the digital industry. The latter indicates that provides digital products or services provided by digital industry for the production of its upstream and downstream non-digital industry, thereby influencing the value creation of the upstream and downstream non-digital industry. This study follows this definition and applies the input-Output (IO) method to measure digitalization from the perspective of input. The key lies in the identification and decomposition of digital factor input, especially when some industries have both digital and non-digital components simultaneously. Whether the implicit digital content in the relevant industries can be fully covered will affect the accuracy and completeness of the measurement results (Xu and Zhang, 2020).

According to the "Statistical Classification of Digital Economy and Its Core Industries (2021)" released by the National Bureau of Statistics of China, the digital economy industry includes five major categories: digital product manufacturing, digital product services, digital technology application, digital element-driven, and digital efficiency improvement. Among them, the core digital industry, namely the digital industrialization part, mainly consists of the first four categories. Based on the "technology" and "service" characteristics of the digital element sectors, this paper redivides and integrates the core industries of the digital economy (Ma et al., 2024), and divides the digital industry into two parts: "ICT manufacturing industry " and "ICT services industry". "ICT manufacturing industry" generally refers to computer hardware in digital infrastructure, corresponding to the communication equipment, computer and other electronic equipment sectors;

1 Please see: "White Paper on China's Digital Economy Development (2017)" [EB/OL] , http://www.caict.ac.cn/kxyj/qwfb/bps/201804/t20180426_158452.htm。

"ICT service industry" encompasses emerging industries such as computer software, telecommunication equipment and services, digital media, and e-commerce. The definition of the digital industry is shown in Table 1.

Table 1. Definition of the Digital Industry

Digital Industry	Forming elements	Content	GB/T 4754-2017	GB/T 4754-2011	Industry categories
ICT Manufacturing Industry	Digital infrastructure	Computer hardware	C-39	C-39	Communication equipment, computers and other electronic devices
ICT Service Industry	Digital infrastructure	Telecommunication equipment and services	I-63 I-64	I-63I-64	Information transmission, software and information technology services
		Computer software	I-65	I-65	
	Digital media	Internet distribution and publishing	R-8624 R-8625 R-8626	R-8524 R-8525 R-8529	Culture, sports and entertainment
		Internet Broadcasting	R-8710 R-8720 R-8730 R-8740 R-8750 R-8760 R-8770	R-8610 R-8620 R-8630 R-8650 R-8660 R-8670	
	E-commerce	Internet Wholesale B2B	F-5193	F-5199	Wholesale and retail trade
		Internet Retail B2C	F-5292	F-5294	

2.2 Accounting framework of Digitalization

As the digital industry is highly involved in the division of labor in production, different production stages are usually carried out in different regions. When quantifying the digitalization, this feature raises a natural question: Can a well-defined IO framework be incorporated to explain the cross-provincial effect of digitalization? To answer this question, this paper constructs a digital accounting framework based on the inter-provincial input-output table of China that distinguishes enterprise heterogeneity, attempting to comprehensively quantify the digitalization level of enterprises in different regions and of different ownerships in China.

Suppose there are G regions, and in each region there are three types of enterprises, namely domestic firms (D), Hong Kong, Macao and Taiwan regions of China-funded enterprises (H), and

multinational enterprises (F)[2]。Z_{sr}^{DH} represents the intermediate input produced by domestic firms in region s and used by Hong Kong, Macao and Taiwan regions of China-funded enterprises in region r. Y_{sr}^{D} represents the final products produced by domestic firms in region s and consumed in region r. X_s^D represents the total output of domestic firms in region s. Va_s^D represents the value added of domestic firms in region s. The direct consumption coefficient matrices of domestic products and imported products can be defined respectively as $A = Z\hat{X}^{-1}$ and $M = IM\hat{X}^{-1}$, where $\hat{X}$ is the diagonal matrix of X. The value-added coefficient vector is defined as $V = Va\hat{X}^{-1}$. ^ represents the diagonalization operation.

Table 2. Inter-Provincial Input-Output table in China distinguishing firm ownership

Input \ Output			Intermediate Use							Final Use				Total Output
			Region 1			⋯	Region G			Region 1	⋯	Region G	Export	
			D	H	F	⋯	D	H	F					
Intermediate Input	Region 1	D	Z_{11}^{DD}	Z_{11}^{DH}	Z_{11}^{DF}	⋯	Z_{1G}^{DD}	Z_{1G}^{DH}	Z_{1G}^{DF}	Y_{11}^{D}	⋯	Y_{1G}^{D}	EX_1^D	X_1^D
		H	Z_{11}^{HD}	Z_{11}^{HH}	Z_{11}^{HF}	⋯	Z_{1G}^{HD}	Z_{1G}^{HH}	Z_{1G}^{HF}	Y_{11}^{H}	⋯	Y_{1G}^{H}	EX_1^H	X_1^H
		F	Z_{11}^{FD}	Z_{11}^{FH}	Z_{11}^{FF}	⋯	Z_{1G}^{FD}	Z_{1G}^{FH}	Z_{1G}^{FF}	Y_{11}^{F}	⋯	Y_{1G}^{F}	EX_1^F	X_1^F
	⋮		⋮	⋮	⋮	⋱	⋮	⋮	⋮	⋮	⋱	⋮	⋮	⋮
	Region G	D	Z_{G1}^{DD}	Z_{G1}^{DH}	Z_{G1}^{DF}	⋯	Z_{GG}^{DD}	Z_{GG}^{DH}	Z_{GG}^{DF}	Y_{G1}^{D}	⋯	Y_{GG}^{D}	EX_G^D	X_G^D
		H	Z_{G1}^{HD}	Z_{G1}^{HH}	Z_{G1}^{HF}	⋯	Z_{GG}^{HD}	Z_{GG}^{HH}	Z_{GG}^{HF}	Y_{G1}^{H}	⋯	Y_{GG}^{H}	EX_G^H	X_G^H
		F	Z_{G1}^{FD}	Z_{G1}^{FH}	Z_{G1}^{FF}	⋯	Z_{GG}^{FD}	Z_{GG}^{FH}	Z_{GG}^{FF}	Y_{G1}^{F}	⋯	Y_{GG}^{F}	EX_G^F	X_G^F
	Import	IM	IM_1^D	IM_1^H	IM_1^F	⋯	IM_G^D	IM_G^H	IM_G^F	Y_1^{IM}	⋯	Y_G^{IM}	0	IM
Value-added			Va_1^D	Va_1^H	Va_1^F	⋯	Va_G^D	Va_G^H	Va_G^F					
Total Input			$(X_1^D)'$	$(X_1^H)'$	$(X_1^F)'$	⋯	$(X_G^D)'$	$(X_G^H)'$	$(X_G^F)'$					

Digitalization refers to the parts of the production process related to the digital industry. From the perspective of forward industrial correlation, it is the value added driven by the digital industry (including the value added of the digital industry itself and the part of the value added of non-digital industries such as chemical and energy sectors that is pulled by the digital industry). From the perspective of backward industrial correlation, it is about how the final output of the digital industry or non-digital industry directly or indirectly drives the value added of the digital industry. When analyzing digitalization issues, people often focus on the use of digital technologies and data in non-digital industries, that is, defining the scale of digitalization from the perspective of backward industrial correlation. Digitalization can be further divided into the direct part (the part directly related to the digital industry) and the indirect part (the part in the non-digital industry that is associated with the digital industry through the connection of upstream and downstream industries).

2 'Multinational enterprises' in this paper refers to foreign-invested enterprises other than those from Hong Kong, Macao and Taiwan regions of China, that is, foreign-invested enterprises with actual foreign capital inflows exceeding 25%. Multinational enterprises and Hong Kong, Macao and Taiwan regions of China-funded enterprises are collectively referred to as foreign-funded enterprises.

From the perspective of backward industrial correlation, the direct part of digitalization is the final products and services produced by the digital industry, and the indirect part is the input of the digital industry to the final products or services of non-digital industries. Based on this, according to Wang et al. (2021), a digital accounting framework distinguishing enterprise heterogeneity was constructed. The digitalization scale and digitalization level from backward perspective can be defined as

$$\begin{aligned} Dig &= Dig\_dir + Dig\_ind = VL\hat{Y}_d + (VL - V_{\bar{d}}L_{\bar{d}})\hat{Y}_{\bar{d}} + \mu ML\hat{Y}_d + \mu(ML - M_{\bar{d}}L_{\bar{d}})\hat{Y}_{\bar{d}} \\ &= \underbrace{\left(VL\hat{Y}_d^D + VL\hat{Y}_d^H + VL\hat{Y}_d^F + \mu ML\hat{Y}_d^D + \mu ML\hat{Y}_d^H + \mu ML\hat{Y}_d^F\right)}_{\text{Direct digitalization scale}} + \\ &\quad (VL - V_{\bar{d}}L_{\bar{d}})\hat{Y}_{\bar{d}}^D + (VL - V_{\bar{d}}L_{\bar{d}})\hat{Y}_{\bar{d}}^H + (VL - V_{\bar{d}}L_{\bar{d}})\hat{Y}_{\bar{d}}^F + \\ &\quad \underbrace{(\mu ML - M_{\bar{d}}L_{\bar{d}})\hat{Y}_{\bar{d}}^D + \mu(ML - M_{\bar{d}}L_{\bar{d}})\hat{Y}_{\bar{d}}^H + \mu(ML - M_{\bar{d}}L_{\bar{d}})\hat{Y}_{\bar{d}}^F}_{\text{Indirect digitalization scale}} \end{aligned} \tag{1}$$

$$D\_rate = Dig/Y' = Dig\_dir/Y' + Dig\_ind/Y' \tag{2}$$

Where subscript d stands for digital industry and $\bar{d}$ stands for non-digital industry. $V_{\bar{d}} = V - V_d$ is the vector of the coefficient of value added for non-digital industries.。A_d and $A_{\bar{d}}$ are the direct consumption coefficient matrices for the digital and non-digital industries, respectively. $L = (I - A)^{-1}$ is the domestic Leontief inverse matrix, which represents the total consumption of output by a certain sector in the Chinese economy for producing an additional unit of the final product. $L_{\bar{d}} = (I - A_{\bar{d}})^{-1}$ is the domestic Leontief inverse matrix after excluding the input of digital industry. $M_{\bar{d}}$ is the matrix of direct consumption coefficients of imports for non-digital industries. $Y_{\bar{d}} = Y - Y_d$ is the vector of final output for non-digital industries[3]. The final output of each sector in each region can be measured by diagonalization. μ is the row vector with all elements being 1. Formula (1) represents the backward digitalization scale. The first six terms are the direct digitalization scale (digital industrialization), and the last six terms are the indirect digitalization scale (industrial digitalization). The specific meanings of the decomposed terms are shown in Table 3. Formula (2) represents the backward digitalization level, that is, the proportion of the digitalization scale of each province and sector in their final output, which is divided into direct digitalization level and indirect digitalization level.

Table 3. Digitalization Decomposition Framework

Production entity / Source of digital input		Domestic-funded enterprise (D)	Hong Kong, Macao and Taiwan regions of China-funded enterprises (H)	Foreign-funded enterprise (F)
Direct digitalization	Domestic digital input	$VL\hat{Y}_d^D$	$VL\hat{Y}_d^H$	$VL\hat{Y}_d^F$
	Imported digital input	$\mu ML\hat{Y}_d^D$	$\mu ML\hat{Y}_d^H$	$\mu ML\hat{Y}_d^F$
Indirect digitalization	Domestic digital input	$(VL - V_{\bar{d}}L_{\bar{d}})\hat{Y}_{\bar{d}}^D$	$(VL - V_{\bar{d}}L_{\bar{d}})\hat{Y}_{\bar{d}}^H$	$(VL - V_{\bar{d}}L_{\bar{d}})\hat{Y}_{\bar{d}}^F$

3 Perform row summation on the final use matrix. At this point, *Y* is the column vector after summing the domestic final use and the export.

	Imported digital input	$(\mu ML - M_{\bar{d}}L_{\bar{d}})\hat{Y}_{\bar{d}}^{D}$	$\mu(ML - M_{\bar{d}}L_{\bar{d}})\hat{Y}_{\bar{d}}^{H}$	$\mu(ML - M_{\bar{d}}L_{\bar{d}})\hat{Y}_{\bar{d}}^{F}$

In order to identify the key driving factors of digitalization development and analyze the role of enterprises of different ownership, this paper uses the structural decomposition analysis (SDA) to decompose the changes in the digitalization level (Dietzenbacher and Los, 1998)。

$$\Delta \mathrm{D\_rate}^{t1-t0} = \mathrm{D\_rate}^{t1} - \mathrm{D\_rate}^{t0}$$

$$= \underbrace{\left(\frac{V^{t1}L^{t1}\hat{Y}_{d}^{t1}}{(Y')^{t1}} - \frac{V^{t0}L^{t0}\hat{Y}_{d}^{t0}}{(Y')^{t0}} + \frac{\mu M^{t1}L^{t1}\hat{Y}_{d}^{t1}}{(Y')^{t1}} - \frac{\mu M^{t0}L^{t0}\hat{Y}_{d}^{t0}}{(Y')^{t0}}\right)}_{\text{①Direct digitalization effect}} +$$

$$\underbrace{\frac{1}{2}\Delta V\left(L^{t1}\hat{y}_{\bar{d}}^{t1} + L^{t0}\hat{y}_{\bar{d}}^{t0}\right) - \frac{1}{2}\Delta V_{\bar{d}}\left(L_{\bar{d}}^{t1}\hat{y}_{\bar{d}}^{t1} + L_{\bar{d}}^{t0}\hat{y}_{\bar{d}}^{t0}\right)}_{\text{②Domestic intensity effect}} +$$

$$\underbrace{\frac{1}{2}\mu\Delta M\left(L^{t1}\hat{y}_{\bar{d}}^{t1} + L^{t0}\hat{y}_{\bar{d}}^{t0}\right) - \frac{1}{2}\mu\Delta M_{\bar{d}}\left(L_{\bar{d}}^{t1}\hat{y}_{\bar{d}}^{t1} + L_{\bar{d}}^{t0}\hat{y}_{\bar{d}}^{t0}\right)}_{\text{③Import intensity effect}} +$$

$$\underbrace{\frac{1}{2}\left((V^{t1}+\mu M^{t1})\Delta L\hat{y}_{\bar{d}}^{t0} + (V^{t0}+\mu M^{t0})\Delta L\hat{y}_{\bar{d}}^{t1} - \left(V_{\bar{d}}^{t1}+\mu M_{\bar{d}}^{t1}\right)\Delta L_{\bar{d}}\hat{y}_{\bar{d}}^{t0} - \left(V_{\bar{d}}^{t0}+\mu M_{\bar{d}}^{t0}\right)\Delta L_{\bar{d}}\hat{y}_{\bar{d}}^{t1}\right)}_{\text{④Structural effect}} +$$

$$\underbrace{\frac{1}{2}\left(V^{t1}L^{t1} + V^{t0}L^{t0} - V_{\bar{d}}^{t1}L_{\bar{d}}^{t1} - V_{\bar{d}}^{t0}L_{\bar{d}}^{t0} + \mu\left(M^{t1}L^{t1} + M^{t0}L^{t0} - M_{\bar{d}}^{t1}L_{\bar{d}}^{t1} - M_{\bar{d}}^{t0}L_{\bar{d}}^{t0}\right)\right)\Delta\hat{y}_{\bar{d}}}_{\text{⑤The proportion effect of the final output of non-digital industries}}$$

$$= f(\Delta dir) + \underbrace{f(\Delta V) + f(\Delta M) + f(\Delta L) + f(\Delta y_{\bar{d}})}_{f(\Delta Ind)} \quad (3)$$

Where $y_{\bar{d}} = Y_{\bar{d}}/Y$ is the share of the final output of non-digital industries in total final output. Δ represents the difference between two periods, that is, the difference between the corresponding matrices of period t1 and period t0. Formula (3) presents the SDA decomposition results of the changes in digitalization level in different periods. The first term $f(\Delta dir)$ on the right side of the equation represents the changes in direct digitalization level, while the second to fifth terms represent the changes in indirect digitalization level, respectively representing the domestic intensity effect, import intensity effect, structural effect, and the proportion effect of the final output of non-digital industries. Specifically, $f(\Delta V)$ reflects the change in the digitalization level resulting from domestic digital input, namely the domestic intensity effect; $f(\Delta M)$ reflects the change in the digitalization level resulting from the digital input of imports, that is, the import intensity effect; $f(\Delta L)$ reflects the change in the digitalization level resulting from the substitution of production technologies, that is, the input-output structure effect; $f(\Delta y_{\bar{d}})$ represents the proportion effect of the final output of non-digital industries. Among them, ΔV can be further decomposed into ΔV^{D}, ΔV^{H} and ΔV^{F}, and ΔM can be decomposed into ΔM^{D}, ΔM^{H} and ΔM^{F}. Thus, the intensity effect can be further decomposed into the intensity effects of domestic firms, Hong Kong, Macao and Taiwan regions of China-funded enterprises and multinational enterprises. ΔL can be decomposed into ΔL^{O} and $\Delta(L - L^{O})$, $L^{O} = (I - A^{O})^{-1}$. $A^{O} = \begin{bmatrix} A^{DD} & 0 & 0 \\ 0 & A^{HH} & 0 \\ 0 & 0 & A^{FF} \end{bmatrix}$ is the matrix of the direct consumption coefficient of domestic products that only includes enterprises of

the same ownership. Thus, the structural effect can be further decomposed into the industrial correlation effect among enterprises of the same ownership and the industrial correlation effect among enterprises of different ownership. $\Delta y_{\bar{d}}$ can be further decomposed into $\Delta y_{\bar{d}}^{D}$, $\Delta y_{\bar{d}}^{H}$ and $\Delta y_{\bar{d}}^{H}$. Thus, the proportion effect of the final output of non-digital industries can be further decomposed into the proportion effect of the final output of non-digital industries of domestic firms, Hong Kong, Macao and Taiwan regions of China-funded enterprises and multinational enterprises.

2.3 Data sources and processing

The basic data used in this paper is the Inter-Provincial Input-Output table of China distinguishing enterprise ownership for 2002, 2007, 2012 and 2017 compiled by Chen et al. (2023), covering 31 provinces and 42 sectors. In order to ensure comparability between years and eliminate the influence of price factors, the input-output table was adjusted for flattening with 2002 as the base period by using the price index published by the National Bureau of Statistics of China. And it was merged into 37 sectors. The specific classification of sectors is shown in Appendix A.

For digital industry data, ICT manufacturing and ICT software can be directly obtained in the table, while digital media and E-commerce need to be split from their respective major industry categories. (1) The division of digital media is specifically divided into two parts: ① Radio, television, film and television sound production: In 2007, 2012 and 2017, the proportion of the value added of "radio, television, film and television sound production" in the national IO table to the value added of the industry category "Culture, sports and entertainment industry" to which it belongs can be directly used. In 2002, since the "Culture, Sports and Entertainment Industry" in the national IO table did not separately distinguish this sub-industry, the proportion of operating income of "Radio, Television, Film and Audio-visual Industry" in the 2004 "China Economic Census Yearbook" was used instead. ② Digital Publishing: It includes "Audio-visual product Publishing", "Electronic Publication Publishing" and "Digital Publishing". The proportion of the operating income of the three subcategories published in the "Analysis of the News and Publishing Industry" is used as the proportion of the value added of digital publishing in the "News and Publishing" category. By combining the proportion of the value added of "News and Publishing" in the value added of "Culture, Sports and Entertainment" in the national IO table, the proportion of digital publishing in the value added of "Culture, Sports and Entertainment" can be obtained. (2) The split of E-commerce refers to the method of Cai and Niu (2021), using the proportion of the total e-commerce sales of the whole society released by the China E-commerce Research Center in the "wholesale and retail trade commodity sales" published by the National Bureau of Statistics to replace the proportion of the e-commerce part in the value added of the wholesale and retail trade.

3 Typical Facts of China's digitalization development

3.1 The scale and level of digitalization at the national level

Based on the results of the digitalization scale and level of various provinces in China from 2002 to 2017, it can be found that the overall digitalization level of China shows a growth trend. This change is mainly driven by the development of the digital industry. During the sample period, the characteristics of the three development stages were significantly different: From 2002 to 2007, with

the rise of the global Internet wave and the rapid growth of China's foreign trade, both the scale and level of digitalization in China showed a high-speed growth trend. The scale of digitalization increased from 1,637.82 billion yuan in 2002 to 13,821.54 billion yuan in 2017, growing by 7.44 times. The digitalization level rose from 11.82% to 21.76%, increasing by approximately 9.9 percentage points. The growth of the digital industry became an important engine for China's economic growth. From 2007 to 2012, affected by the financial crisis, the development of China's digital economy began to stabilize. Although the digital industry was impacted, the level of industrial digitalization continued to grow steadily, and the transformation effect of digital technology on traditional industries was more fully exerted. From 2012 to 2017, the digital economy ushered in a new era of all-round development - the Internet 4.0 stage. China's digital economy once again entered a period of rapid growth. The ICT industry developed rapidly, and traditional industries began to accelerate their transformation towards digitalization, networking and intelligence. In 2017, the industrial digitalization level of China reached 8.3%, an increase of 3.6 percentage points compared with 2002. It can be seen that the integration degree of information technology and the real economy has significantly improved.

There are significant differences in the digitalization of enterprises of different ownerships. According to the right chart in Figure 2, it can be found that the digitalization levels of Hong Kong, Macao and Taiwan regions of China-funded enterprises and multinational enterprises within China are particularly outstanding, reaching 45.7% and 42.9% respectively in 2017. Moreover, the final digital output scale created by foreign capital accounts for more than 30% of the national total. It has driven the overall development of digitalization in China. From the perspective of the changing trend, from 2002 to 2017, the digitalization level of Hong Kong, Macao and Taiwan regions of China-funded enterprises increased by 19.6 percentage points, especially the direct digitalization level grew significantly. It is evident that in recent years, the Guangdong-Hong Kong-Macao Greater Bay Area has achieved remarkable results in digital transformation, providing channels and policy support for Hong Kong, Macao and Taiwan regions of China-funded enterprises to enter the Chinese market. By comparing the digitalization levels of enterprises of different ownerships across the country, it can be found that the digitalization levels of enterprises funded by Hong Kong, Macao and Taiwan regions of China and multinational enterprises are significantly higher than those of domestic firms. In 2002, they reached 26.0% and 35.9% respectively, which were 18.9 percentage points and 28.8 percentage points higher than those of domestic firms. This is because foreign-funded enterprises have certain advantages in both the investment in digital equipment and the utilization of information technology for digital transformation. In contrast, domestic firms were initially limited by factors such as technological level and insufficient investment, resulting in a significant digital divide among enterprises. Since 2007, with China's vigorous support for the independent innovation of domestic enterprises, the digital transformation of domestic firms in traditional industries has been continuously advanced, and this gap has narrowed. However, compared with foreign-funded enterprises, domestic firms are still at a relatively primary level in the introduction and application of digital technology, and the differences in digitalization levels among enterprises remain very significant.

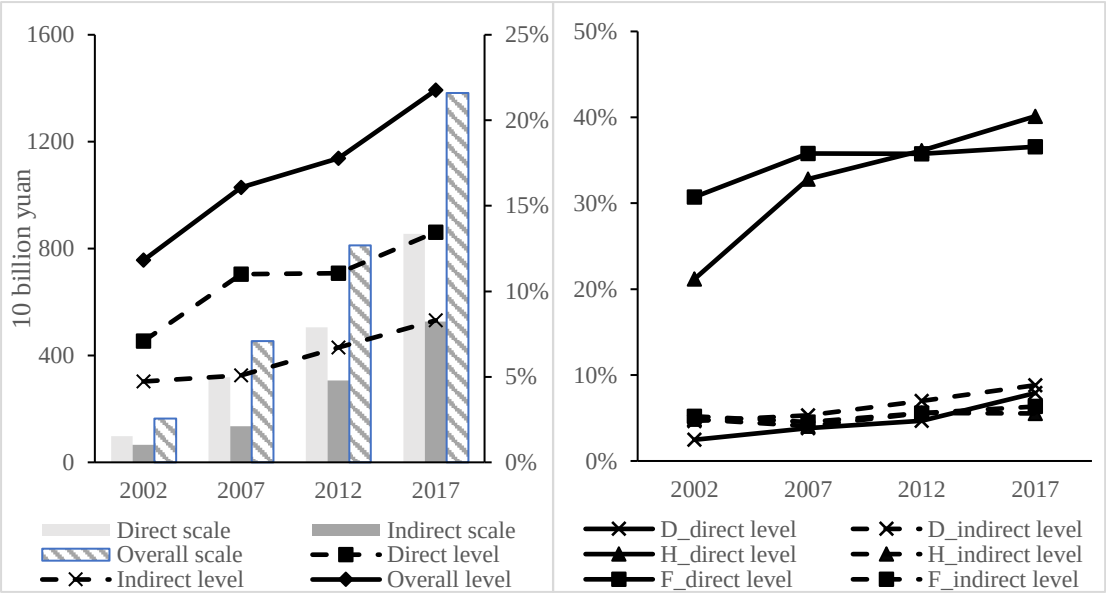

Figure 2. China's overall digitalization level (left) and the digitalization level of different types of enterprises (right)

3.2 Regional differences and Composition of China's digitalization level

(1) Differences among regions

A further analysis of the digitalization development in different regions of China reveals the prominent phenomenon of the digital divide among regions. As shown in Table 4, the digitalization level of the eastern region, especially the Pearl River Delta urban agglomeration, the Yangtze River Delta urban agglomeration and the Beijing-Tianjin region, leads the country. In 2017, the digitalization level of the eastern region reached 24.7%, exceeding the national average (21.8%). Among them, Beijing, Guangdong, Shanghai and Jiangsu maintained their leading positions in the top four. In 2017, the total scale of their digital economy reached 6.7 trillion yuan, accounting for 48.2% of the national digital economy scale. This is relatively close to the result obtained by Han et al. (2021). Compared with the eastern region, the digitalization development in the central and western regions lags behind relatively. In 2017, the digitalization levels in the central and western regions were 18.34% and 18.29% respectively, lagging behind the national average by 3.42 and 3.47 percentage points, and lagging behind the eastern region by 6.35 and 6.40 percentage points respectively. The digitalization level in Northeast China is significantly lower than that in the eastern regions. The industrial characteristics of focusing on agriculture and traditional heavy industry make Northeast China the most urgent area for digital transformation at present in China. It can be seen from this that China's digitalization shows an unbalanced development at the regional level, and the phenomenon of regional digital divide is very prominent. However, under the influence of various factors such as policy adjustments and industry development, this phenomenon shows a fluctuating development trend. During the early period, with the rapid development of the Jiangsu-Zhejiang-Shanghai region and the Pearl River Delta region, the differences in digitalization levels among regions in China, especially between the eastern region and the central and western regions, increased significantly from 2002 to 2007. However, since 2007, the digitalization of some provinces in the central and western regions, such as Sichuan and Chongqing, has developed rapidly,

driving the overall digitalization level of the central and western regions to continuously improve. It has become a new growth point of the domestic digital economy and has also narrowed the gap in digitalization levels between the east and the west.

Table 4. Digitalization Level in Different Regions of China from 2002 to 2017[4]

Year	Indicator	Eastern China	Central China	Western China	Northeast China
2002	Direct digitalization	10.1%	2.2%	2.6%	3.7%
	Indirect digitalization	5.3%	3.2%	4.1%	4.7%
	Total digitalization	15.4%	5.4%	6.7%	8.4%
2007	Direct digitalization	16.3%	4.0%	3.8%	4.9%
	Indirect digitalization	4.6%	2.9%	2.7%	2.9%
	Total digitalization	21.8%	8.3%	8.3%	9.2%
2012	Direct digitalization	14.1%	6.3%	7.3%	4.5%
	Indirect digitalization	5.5%	4.1%	3.5%	3.2%
	Total digitalization	21.1%	12.9%	13.4%	11.0%
2017	Direct digitalization	16.8%	8.5%	10.1%	5.7%
	Indirect digitalization	9.3%	5.8%	7.3%	5.0%
	Total digitalization	24.7%	18.3%	18.3%	13.7%

(2) Differences within the region

There is also an unbalanced development phenomenon in the digitalization process of enterprises of different ownerships within the region. The unbalanced distribution of foreign capital has become an important reason for the emergence of the regional digital divide. From the perspective of spatial distribution, the eastern region, which has a high level of economic development, a large domestic market scale, and the most complete industrial chain, is more favored by foreign capital. In 2017, the digital final output scale created by foreign capital in the eastern region reached as high as 83%. Multinational enterprises that carry out production activities in the eastern region often have more advanced digital production technologies. In 2017, their digitalization level reached 44.9%, which was higher than that of local firms (17.8%) and multinational enterprises investing in other regions. The high concentration of foreign capital in the eastern region has enabled the overall digital transformation process in China's southeast coastal areas to take the lead over other provinces.

For the central and western regions, the layout of foreign capital is constantly expanding, creating new growth space for local industrial upgrading. In 2017, the digitalization levels of the central and western regions reached 66.2% and 58.2% respectively, far higher than that of domestic firms. Furthermore, it can be found that in recent years, the layout of foreign investment has gradually been adjusted in terms of space. Due to the unsustainable low-cost labor resources and industrial land resources in the economically developed southeast coastal areas, foreign investment in the Chinese mainland shows a trend of shifting to the southwest region, which has led to a continuous

4 According to the classification of the National Bureau of Statistics of China, the eastern region includes Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong and Hainan. The central region includes Shanxi, Anhui, Jiangxi, Henan, Hubei and Hunan. The western region includes Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Tibet, Shaanxi, Gansu, Qinghai, Ningxia and Xinjiang. The Northeast region includes Liaoning, Jilin and Heilongjiang.

rise in the digitalization level of Hong Kong, Macao and Taiwan regions of China-funded enterprises in the central and western regions. After 2007, it surpassed that of the eastern region. However, Hong Kong, Macao and Taiwan regions of China-funded enterprises investing in the central and western regions have not yet generated significant impetus for the digital transformation of local traditional industries. In 2017, their indirect digitalization levels were only 3.8% and 4.0% respectively, far lower than the national average.

Table 5. Digitalization Level of Different types of Enterprises within China from 2002 to 2017

Region	Year	D			H			F		
		Total	Direct	Indirect	Total	Direct	Indirect	Total	Direct	Indirect
Eastern China	2002	8.4%	3.1%	5.3%	27.0%	21.9%	5.0%	38.8%	33.4%	5.4%
	2007	10.6%	4.6%	6.0%	37.3%	33.1%	4.2%	47.2%	42.5%	4.7%
	2012	12.9%	5.5%	7.4%	37.4%	31.1%	6.2%	43.8%	38.1%	5.7%
	2017	17.8%	8.6%	9.3%	42.3%	36.4%	5.9%	44.9%	38.7%	6.2%
Central China	2002	4.7%	1.5%	3.2%	14.2%	11.8%	2.5%	18.6%	15.4%	3.2%
	2007	7.2%	2.9%	4.4%	31.4%	28.9%	2.5%	20.6%	16.9%	3.7%
	2012	10.8%	4.1%	6.8%	62.2%	58.9%	3.3%	18.6%	13.9%	4.6%
	2017	16.0%	7.8%	8.2%	66.2%	62.3%	3.8%	20.9%	15.4%	5.5%
Western China	2002	6.2%	2.1%	4.1%	14.3%	10.2%	4.1%	20.2%	15.2%	4.9%
	2007	7.2%	2.7%	4.6%	33.1%	30.2%	2.9%	27.7%	24.6%	3.1%
	2012	9.8%	3.5%	6.3%	72.1%	70.2%	1.9%	39.3%	35.1%	4.2%
	2017	15.7%	7.3%	8.4%	58.2%	54.2%	4.0%	41.4%	35.5%	5.9%
Northeast China	2002	6.2%	1.3%	4.8%	21.9%	18.9%	3.0%	23.7%	19.5%	4.2%
	2007	7.4%	2.9%	4.5%	30.0%	27.5%	2.5%	21.1%	17.8%	3.3%
	2012	9.9%	3.2%	6.7%	31.8%	28.1%	3.8%	17.1%	11.7%	5.4%
	2017	13.2%	5.0%	8.1%	28.9%	24.5%	4.4%	15.7%	8.5%	7.2%

3.3 Industry Characteristics

Based on the above analysis, we further discuss the industry characteristics of enterprises of different ownerships to explore whether the heterogeneous influence of foreign capital on the differences in regional digitalization levels stems from the industry characteristics they are engaged in. According to Table 6, the differences in digitalization levels among enterprises of different ownerships are mainly reflected in high-tech manufacturing and productive service industries. In 2017, the digitalization levels of domestic firms, Hong Kong, Macao and Taiwan regions of China-funded enterprises, and multinational enterprises in the high-tech manufacturing industry were 22.6%, 63.6% and 50.2% respectively, and those in the production service industry were 38.3%, 67.3% and 58.2% respectively. It can be clearly observed that there is a considerable gap between foreign-funded enterprises (Especially Hong Kong, Macao and Taiwan regions of China) and domestic firms. Although with the extension of the value chain and the upgrading of industry, the

digitalization level of domestic firms in China's high-tech manufacturing sector has significantly improved in recent years (increased by 6.2 percentage points compared with 2002), the gap between them and foreign-funded enterprises still cannot be ignored. The road to digital transformation for domestic firms is still long and arduous.

The main reason for the difference in digitalization levels between domestic and foreign-funded enterprises is the direct effect of the digital industry. Take high-tech manufacturing as an example. In 2017, the direct digitalization level gap between Hong Kong, Macao and Taiwan regions of China-funded enterprises and multinational enterprises and domestic firms was as high as 45.5 and 31.2 percentage points respectively. However, the industrial digitalization level was 4.5 and 3.6 percentage points lower than that of domestic firms. The digitalization level of traditional manufacturing industries in domestic firms is on the rise across the board and has gradually replaced digital industrialization as the main form of digital economy development. Overall, the digital integration approach of foreign capital in traditional manufacturing industry is more about providing digital input to domestic firms to promote their production transformation. However, there is still a considerable gap between the digitalization level of domestic firms and that of foreign-funded enterprises. During the process of digital transformation, it is necessary to further unleash the potential for digital upgrading of domestic firms in the manufacturing sector. By enhancing the application and integration of digital technologies and strengthening the innovation capabilities at key nodes, the digital gap between domestic and foreign-funded enterprises can be narrowed, thereby achieving an overall improvement in the digital economy.

Table 6. Industry characteristics of digitalization levels of different enterprises in 2017

Sector	Total		D		H		F	
Group	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect
AGR	-	3.9%	-	3.9%	-	4.3%	-	5.4%
MIN	-	7.6%	-	7.3%	-	-2.0%	-	10.0%
LTI	-	6.3%	-	6.4%	-	6.3%	-	5.7%
MTI	-	6.1%	-	6.3%	-	5.3%	-	5.9%
HTI	28.0%	7.9%	13.0%	9.6%	58.6%	5.0%	44.2%	5.9%
EGW	-	7.4%	-	7.7%	-	4.5%	-	5.3%
CON	-	8.0%	-	8.0%	-	6.8%	-	8.5%
LSI	0.9%	8.2%	0.9%	8.3%	0.7%	6.0%	0.5%	5.8%
PSI	29.2%	11.8%	26.1%	12.2%	61.1%	6.2%	46.5%	11.7%

Note: The sector classification is detailed in Appendix A.

While promoting the role of foreign capital in China's digital transformation and upgrading, it is also necessary to pay attention to the balance of its regional industrial layout. With the continuous expansion of the scope, fields and levels of China's opening up to the world and the continuous upgrading of the manufacturing structure, foreign capital is accelerating the release of the digital potential of manufacturing in the central and western regions, promoting the digital transformation process, constantly narrowing the gap with the southeast coastal regions and achieving a "curve overtaking". The results in Table 7 show that from 2002 to 2017, the digitalization level of Hong Kong, Macao and Taiwan regions of China-funded enterprises and multinational enterprises engaged in manufacturing production in the central and western regions increased significantly. Especially for Hong Kong, Macao and Taiwan regions of China-funded enterprises in the high-tech

manufacturing industry, their digitalization level jumped from 25.8% to 84.5%. It exceeded the corresponding digitalization level in the eastern region that year (58.3%). Foreign investment has also accelerated the digital development of modern service industries in the central and western regions. Compared with 2002, the digitalization levels of Hong Kong, Macao and Taiwan regions of China-funded enterprises and multinational enterprises have all improved, and their digitalization levels are all higher than those in the eastern region. It can be seen that foreign capital has played a significant role in promoting the overall digital development of the central and western regions in China, narrowing the gap in digitalization levels between the central and western regions and the eastern region. However, at the same time, it has also exacerbated the imbalance in digitalization among industries within the region. In 2017, the differences in digitalization levels among industries in the central and western regions were generally higher than those in 2002. The inflow of foreign capital into the high-tech manufacturing sector enabled its digitalization level to be significantly ahead of other industries.

Table 7. Industry Characteristics of digitalization levels of different enterprises in Eastern China and Central and Western China

Region	Sector Group	2002				2017			
		Total	D	H	F	Total	D	H	F
Eastern China	AGR	1.7%	1.7%	2.8%	0.0%	4.1%	4.1%	4.2%	7.8%
	MIN	4.7%	4.7%	5.2%	2.8%	6.8%	13.9%	1.0%	8.3%
	LTI	3.4%	3.4%	3.2%	3.5%	6.2%	6.3%	6.4%	5.7%
	MTI	5.2%	4.9%	5.5%	6.1%	6.2%	6.5%	5.3%	6.0%
	HTI	39.1%	18.6%	50.7%	58.9%	38.7%	22.7%	58.3%	52.5%
	EGW	3.4%	3.4%	2.7%	4.5%	8.7%	9.2%	3.9%	5.5%
	CON	4.7%	4.7%	0.0%	0.0%	7.5%	7.5%	7.3%	7.5%
	LSI	7.2%	7.4%	5.5%	5.9%	7.8%	8.0%	6.1%	5.8%
	PSI	19.9%	16.0%	57.7%	36.9%	42.2%	38.9%	65.8%	58.3%
Central and Western China	AGR	1.3%	1.3%	0.0%	2.4%	3.9%	3.9%	4.3%	6.8%
	MIN	1.2%	1.2%	68.7%	-0.6%	7.3%	7.3%	10.4%	10.1%
	LTI	2.4%	2.3%	2.8%	3.2%	6.6%	6.6%	6.3%	6.3%
	MTI	2.9%	2.8%	3.4%	3.9%	6.2%	6.2%	6.1%	5.3%
	HTI	14.4%	13.3%	24.8%	22.5%	32.3%	24.2%	84.5%	40.1%
	EGW	4.2%	4.0%	3.8%	7.3%	6.3%	6.4%	5.8%	5.0%
	CON	3.5%	3.5%	0.0%	0.0%	8.7%	8.8%	6.4%	11.6%
	LSI	5.3%	5.3%	3.7%	5.2%	10.9%	10.9%	9.1%	9.1%
	PSI	17.1%	13.7%	67.1%	62.0%	39.2%	37.7%	72.1%	60.5%

4 Trends and driving factors of China's Digitalization Level

In order to further explore the reasons influencing the digital development in China, this paper further conducts a quantitative analysis of the driving factors of China's digitalization level based on the Structural Decomposition Analysis (SDA) method, thereby identifying the key driving forces for the development of China's digitalization level and exploring the basic factors that cause regional digital divide. In particular, by analyzing the roles played by multinational enterprises in this process,

it is conducive to giving better play to the positive role of foreign capital in the process of digital transformation in our country.

As shown in Figure 3, the changes in the direct digitalization level from 2002 to 2017 were the main driving factor for the overall increase in China's digitalization level, while the impact of changes in the industrial digitalization level was relatively limited. Looking at different time periods, from 2002 to 2007, the development of the digital economy was more achieved through the direct development of digital technologies or digital industries. Therefore, the rise in China's digitalization level was greatly directly influenced by the digital industry (the direct digitalization effect was 2.95%). As the digital economy enters the stage of integration with the real economy, the impact of changes in indirect digitalization levels gradually increases. During the period from 2012 to 2017, the proportion of industrial digitalization effects approached that of digital industrialization effects. The two began to work together to promote the development of China's digital economy. Furthermore, by breaking down the indirect effects, it can be found that the proportion effect of the final output of non-digital industries of early multinational enterprises is the most significant factor promoting China's digital development. Multinational enterprises provide advanced technology and financial support for production by entering the traditional industry markets in China, injecting new impetus into the improvement of China's digitalization level. During this period, the proportion effect of the final output of non-digital industries of domestic firms was also a relatively important influencing factor. As the dominant type of enterprise within China, domestic firms covered the majority of the Chinese market. The expansion of their layout in non-digital industries would significantly boost the production of the digital sector, and thereby affect the supply of digital components to downstream sectors and consumers.

Foreign capital is creating new space for China's digital development, and the joint production between foreign capital and domestic enterprises is gradually playing a positive role. With the intensification of competition among foreign-funded enterprises in China and the transformation of investment strategies of multinational enterprises, the contribution of the demand-side effect of Hong Kong, Macao and Taiwan regions of China-funded enterprises and foreign-funded enterprises to the overall digital development has gradually weakened, while the structural effect has strengthened. The absolute value of the structural effect between domestic and multinational enterprises from 2002 to 2007 and from 2007 to 2012 was relatively small. However, with the development of digital technology and the adjustment of the layout of foreign investment, the industrial correlation effect between Hong Kong, Macao and Taiwan regions of China-funded enterprises, multinational enterprises and domestic firms from 2012 to 2017 brought a 2.6% increase in the digitalization level. It has become the top factor driving the rise of China's digitalization level. On the one hand, the investment of multinational enterprises in China has increasingly strong requirements for supporting production, and they have begun to seek strategic models that combine technological investment with development support. The structural effect among enterprises of the same ownership has started to play an important role in the overall digitalization development of China. On the other hand, as multinational enterprises expand and deepen their production in China, they have developed close industrial connections with domestic upstream and downstream firms in the process of production and operation. This industrial correlation provides a demonstration effect for the production of domestic firms in our country. Advanced products, management experience, production technology and professional talents enter the domestic value chain production through

upstream and downstream connections, leading to the generation of technology spillover effects and thus promoting the digital transformation and upgrading of China. However, neither the domestic intensity effect nor the import intensity effect has brought a significant positive impact on the rise in the digitalization level. In recent years, the domestic intensity effect of domestic firms has even dropped to a negative value at one point. It can be seen that for domestic firms, promoting the development of digital technology is an effective way to facilitate the digital transformation of this group.

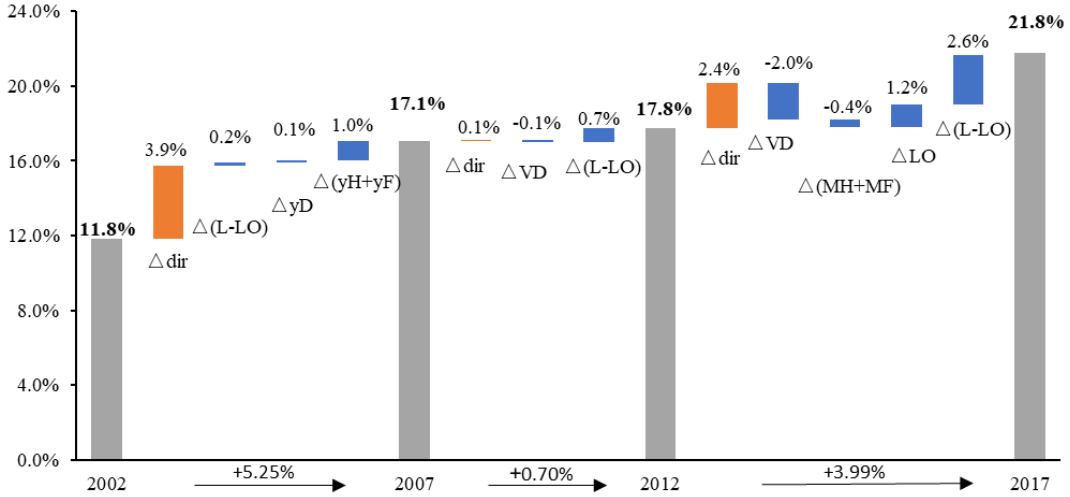

Figure 3. Driving factors of changes in China's digitalization level from 2002 to 2017

Note: The orange part represents the direct effect, and the blue part represents the indirect effect. △VD, △(VH+VF), △MD, △(MH+MF), △LO, △(L-LO), △yD, △(yH+yF) respectively represent the domestic intensity effect of domestic firms, the domestic intensity effect of multinational enterprises, the import intensity effect of domestic firms, the import intensity effect of multinational enterprises, the industrial correlation effect among enterprises of the same ownership, the industrial correlation effect among enterprises of different ownership, the proportion effect of the final output of non-digital industries in domestic firms, and the proportion effect of the final output of non-digital industries in multinational enterprises. Here, multinational enterprises include those from Hong Kong, Macao and Taiwan regions of China. Only the items with a variation range greater than ±0.1% are shown in the figure.

In order to explore the main factors causing the changes in digitalization levels among different regions and the effective causes of the digital divide, the driving factors of the changes in digitalization levels among the major regions of China (the east, the central and western regions, and the Northeast) are further decomposed. From the decomposition results of the eastern, central and western regions and the northeastern region of China from 2002 to 2017, it can be found that the main factors influencing the differentiated digital development in the eastern region and the central and western regions are direct effects, while the main factors influencing the digitalization level in the northeastern region are indirect effects. Among them, the proportion effect of the final output of non-digital industries of multinational enterprises is the dominant factor driving the improvement of the indirect digitalization level in various regions. The domestic intensity effect of domestic firms and the correlation effect between domestic firms and foreign-funded enterprises have become one of the key reasons for the emergence of the regional digital divide. According to

Figure 4, the intensity effect and structural effect of digitalization level in different regions vary significantly. Near 0.9% improvement in digitalization level in the eastern region is triggered by the industrial correlation effect between domestic and foreign enterprises. This fully demonstrates that foreign-funded enterprises in the eastern region are gradually integrating into the local value chain system of China. By providing intermediate products to upstream and downstream partners, they have achieved technology spillover and demonstration effects, thereby driving the overall improvement of digitalization level in the eastern region. During this research period, the domestic intensity effect of domestic firms increased by 0.28%. On the contrary, in the central and western regions and the northeastern region, the digitalization level was less affected by the industrial correlation effect between domestic and foreign enterprises in 2017, and the domestic intensity effect of domestic firms showed a significant hindering effect. It can be seen that the current development of digitalization in the central and western regions and the northeastern region is still in its infancy. Due to the limitations of geographical location and transportation, the production mode is mostly dominated by domestic firms within the province, and the cooperative relationship between domestic and foreign-funded enterprises is relatively weak. In the future, as Hong Kong, Macao and Taiwan regions of China-funded enterprises and multinational enterprises migrate to the southwest of China, the central and western regions may become new production clusters. During the process of digital transformation, it is necessary to grasp the key points and difficulties, and start from the main constraints such as the digitalization intensity of domestic firms and the industrial connection between domestic and foreign-funded enterprises, to promote the coordinated and orderly advancement of digitalization in the eastern, central and western regions.

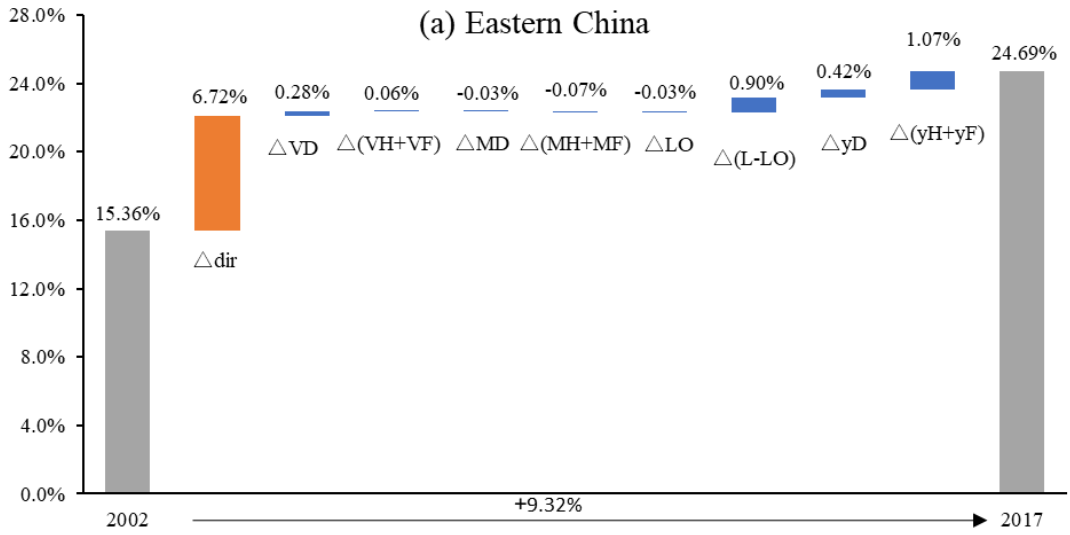

Figure 4. Influencing factors of the changes in digitalization levels in different regions of China

Note: Figures a-c respectively show the decomposition results of the changes in digitalization levels in Eastern China, Central and Western China, and Northeast China from 2002 to 2017. The meanings of the indicators are consistent with those in Figure 3.

5 Further discussion: The impact of China's digitalization development on the division of labor in the domestic value chain

With the vigorous development of the digital economy, digital technology has gradually permeated and extended into traditional industries. Disruptive innovative changes are taking place in many links, from R&D and design to production and manufacturing, and even sales and logistics, driving the domestic value chain division of labor pattern to evolve towards networking, informatization and collaboration. Compared with the traditional economic development model, traditional industries, especially manufacturing industries, have replaced labor, capital and other production factors with "data", fundamentally changing the organizational structure and driving factors of

industrial development. Moreover, they can rely on the aggregation and sharing of massive data information to break the "shackles" set by physical distance and institutional environment for supply and demand matching, which provide opportunities for building a domestic value chain division of labor network. This section focuses on exploring the impact and mechanism of the improvement of digitalization level on the depth of division of labor in the domestic value chain. The empirical model is set as follows:

$$PNVC_{i,s,t} = \alpha_0 + \beta_1 Digisity_{i,s,t} + \gamma_n Controls_{i,s,t} + D_i + D_s + D_t + \varepsilon_{i,s,t} \quad (4)$$

Formula (4) examines the impact of digitalization level on the trade scale of the domestic value chain. The subscripts (i, s, t) represent (region, industry, year). $Digisity$ represents the core explanatory variable, that is, the digitalization level by region and industry obtained based on the production decomposition framework in section 3. $PNVC$ represents the explained variable, the depth of domestic value chain division of labor. Drawing on the decomposition framework by Sheng et al. (2020) and Li and Pan (2016), the depth of domestic value chain division of labor at the regional-industry level is defined as the sum of the forward participation rate and the backward participation rate of the domestic value chain. $Controls$ represents a series of control variables that may affect the depth of division of labor in the domestic value chain. It mainly includes the consumption level of residents, the level of regional innovation, the degree of opening up, the degree of government intervention, infrastructure and population density. The data of control variable are sourced from "China Statistical Yearbook", "China Population Statistical Yearbook", provincial statistical yearbooks, etc. The missing data are filled in using the linear interpolation method. Furthermore, time-fixed effects D_t, regional fixed effects D_i, and industry-fixed effects D_s are added to control the estimation biases that may be caused by non-observable factors that do not change over time. $\varepsilon_{i,s,t}$ represents the random disturbance term.

5.1 Baseline Regression and Heterogeneity Analysis

Table 8 reports the average impact of digitalization level on the depth of division of labor in the domestic value chain, as well as its regression results in different regions, industries, and digital types. In column (1), only the relationship between the core explanatory variable digitalization level and the depth of division of labor in the domestic value chain is focused on. The results show that the regression coefficient of the digitalization level is significantly positive. After adding the control variable in column (2), the direction, size and significance level of coefficient have not changed significantly, and they are still significantly positive at the 1% significance level. It can be seen that the development of digitalization will be beneficial to the deepening of the division of labor in the domestic value chain.

In order to explore whether there are significant differences in the above-mentioned economic effects in terms of industry structure, regional economy, digitalization types, etc., this paper conducts heterogeneity analyses on different types of industries, regions, and digitalization levels respectively. ① **Industry heterogeneity.** Referring to Guan et al. (2016), labor-intensive manufacturing industry and non-labor-intensive manufacturing industry were selected for group regression. The regression results are shown in columns (3) and (4). The improvement of the digitalization level of technology-intensive and capital-intensive manufacturing industries has had a significant positive impact on the depth of division of labor in the domestic value chain, while the

regression result of labor-intensive manufacturing industries is not significant. On the one hand, traditional labor-intensive industries have long relied on labor empowerment. The digitalization of manufacturing is difficult to change the industrial attributes through labor substitution. Therefore, the benefits brought by technological innovation to them are limited. On the other hand, technology-intensive and capital-intensive industries already have the underlying logic for digital development and are highly sensitive to innovation activities. As digital investment gradually increases, they have the ability to incorporate the "digital dividend" into the process of resource allocation, making production division of labor more refined and rationalized. ② **Regional heterogeneity.** Columns (5) and (6) present the impact of digitalization in different regions of China on the depth of domestic value chain division of labor. It shows that digitalization can effectively promote the deepening of domestic value chain division of labor in the central and western regions with relatively low economic development level. A possible explanation for this result is that with the rapid popularization of digital technology, the radius of resource cooperation and the industrial spatial layout have been greatly expanded, promoting production collaboration between the central and western regions and other regions. ③ **Heterogeneity of digital types.** Columns (7) and (8) present the regression results of heterogeneity analysis for different types of digitalization. It can be seen that both direct and indirect digitalization can contribute to the deepening of the division of labor in the domestic value chain, and this effect is more obvious in the latter. The most intuitive reason is that the indirect effects of digitalization widely radiate to all upstream and downstream industries associated with it, and can bring systematic and overall enabling effects to the division of labor in the value chain. This regression result suggests that it is necessary to accelerate the pace of empowering traditional manufacturing with digital technology, and thereby serve the specialized division of labor and cooperation among regions, adding impetus to the construction of a domestic value chain division of labor system at a higher quality and level.

Table 8. Results of Baseline Regression and heterogeneity Analysis

	(1)	(2)	(3) Labor-intensive	(4) Non-labor-intensive	(5) Eastern China	(6) Central and Western China	(7) Direct digitalization	(8) Indirect digitalization
Digisity	0.238***	0.244***	-0.028	0.311***	-0.041	0.260***		
	(3.28)	(3.33)	(-0.09)	(4.37)	(-0.02)	(3.06)		
Dirisity							0.205**	
							(2.42)	
Indirisity								0.337**
								(2.43)
Cons	0.234***	-0.100	0.241	-0.340	-7.845	-0.403	-0.090	-0.071
	(28.40)	(-0.32)	(0.46)	(-0.89)	(-1.09)	(-0.87)	(-0.29)	(-0.22)
Controls	Y	Y	Y	Y	Y	Y	Y	Y
Fixed effect	Y	Y	Y	Y	Y	Y	Y	Y

N	1800	1800	720	1080	660	1140	1800	1800
R^2	0.399	0.405	0.427	0.438	0.494	0.339	0.403	0.403

Note: (1) The numbers in parentheses are the t-statistics when using robust standard errors; (2) * indicates p < 10%, ** indicates p < 5%, *** indicates p < 1%; (3) All results controlled for the fixed effects at the year, region and industry levels.

5.2 Mechanism analysis

Driven by the new generation of information technology revolution, the digital economy has broken the temporal and spatial limitations of economic activities, effectively broadened the geographical boundaries of traditional industries, and can expand the scope of commodity exchange to the distant market, which is conducive to achieving the economies of scale brought by network externalities. Secondly, digital technology has broadened the opportunities and channels for technological learning, accelerated the formation of innovative concepts and product ideas in enterprises, and provided an opportunity for enterprises to imitate cutting-edge innovations and grasp the direction of technological changes. Furthermore, the coordinated development of the digital economy and manufacturing has given rise to numerous new industries, new business forms and new models, fundamentally reshaping the organizational structure and competitive edge of the manufacturing industry. Taking all the above considerations into account, this paper refers to the "two-step method" proposed by Jiang (2022) to construct a mechanism test model, and explores the potential mechanism by which digitalization affects the depth of division of labor in the domestic value chain from three perspectives: economies of scale, technological innovation, and industrial structure upgrading.

Table 9 reports the regression results of the economies of scale effect, the technological innovation effect and the industrial structure upgrading effect. ① **Economies of scale effect.** We use the total output value at the regional and industry level as the proxy variable of the economies of scale effect. It was found that the improvement of digitalization level can help achieve rapid expansion of the local market scale, reduce marginal production costs, deeply strengthen the production division of labor connections among upstream and downstream industries in different regions, and thereby generally improve the quality of division of labor in each link of the value chain. This view is similar to the conclusion of Wang et al. (2023), further verifying the existence of the influence mechanism of economies of scale. ② **Technological innovation effect.** This paper conducts a regression using the proportion of research and development and testing expenses of large-scale industrial enterprises in the gross domestic product. It is found that the estimated coefficient of digitalization level is significantly positive, confirming its strong correlation with technological innovation. This will drive the pattern of division of labor in domestic value chain to evolve towards fragmentation and regionalization, thereby enhancing the participation of different regions in the domestic value chain division of labor system. ③ **Effect of industrial structure upgrading.** This paper extends the revealed comparative advantage (RCA) index to the regional level, and measures the comparative advantages of each region-industry in participating in domestic inter-regional trade from the perspectives of total value and value added. The specific calculation method is shown in Appendix B. It can be found that no matter from which perspective the indicators of industrial structure upgrading are measured, the improvement of digitalization level can assist each region and industry in accurately identifying their comparative advantage and roles in economic development. Lay an

important foundation for the cooperative connection between the upstream and downstream links of the domestic value chain.

Table 9. The Influence Mechanism of Digitalization on the Depth of Division of Labor in the Domestic value Chain

	(1)	(2)	(3)	(4)
	Economies of scale	Technological innovation	Industrial structure upgrading	
			RCA_O	RCA_NVC
$Digisity$	8.886***	25.124***	2.402**	1.649**
	(15.95)	(2.64)	(2.58)	(2.55)
Cons	7.801***	-154.760***	-5.259	-4.418
	(3.22)	(-3.75)	(-1.30)	(-1.57)
Controls	Y	Y	Y	Y
Year fixed effect	Y	Y	Y	Y
Regional fixed effect	Y	Y	Y	Y
Industry fixed effect	Y	Y	Y	Y
N	1800	1800	1800	1800
R^2	0.813	0.780	0.287	0.370

Note: (1) The numbers in parentheses are the t-statistics when using robust standard errors; (2) * indicates p < 10%, ** indicates p < 5%, *** indicates p < 1%; (3) All results controlled for the fixed effects at the year, region and industry levels.

6 Conclusions

Based on the multi-regional input-output model, this paper constructs a digital accounting framework from the perspective of backward industrial correlation and defines the indicators of China's digitalization effect and digitalization level. It measures China's digitalization level from the three dimensions of region - enterprise - industry, thereby discussing the issues of "regional digital divide" and "enterprise digital divide" arising in the process of China's digitalization development. Subsequently, the influencing factors of China's digitalization level were analyzed by using the structural decomposition method, and the impact of digital development on the division of labor in the domestic value chain was explored. It shows that: (1) There is a distinct regional digital divide phenomenon in China, and the digitalization level of the eastern region leads the country. (2) There are significant differences in digitalization levels among different types of enterprises. The digitalization level of multinational enterprises (especially those from Hong Kong, Macao and Taiwan regions of China) is significantly higher than that of domestic firms. Foreign capital is accelerating the digital transformation of traditional manufacturing and modern service industries in China's central and western regions, constantly narrowing the gap with the southeast coastal areas, and achieving a "curve overtaking" in digital transformation. (3) The changes in the level of digital industrialization are an important driving factor for the overall rise in China's digitalization level and also the main cause of regional digital divide. In addition, the joint production between multinational enterprises and domestic firms is gradually playing a positive role,

creating new development space for China's digital transformation. (4) The improvement of digitalization level can significantly promote the deepening of domestic value chain division of labor, mainly through the effects of economies of scale, technological innovation and industrial structure upgrading. This effect is significant in technology and capital-intensive manufacturing industries and the central and western regions.

Based on the above conclusions, this paper puts forward the following suggestions: First, formulate strategies for the integrated development of the digital economy and the real economy based on local conditions, and strive to achieve coordinated digital development. Under the new development pattern, there are obvious differences in the characteristics of regional digital development within China, and the phenomenon of digital divide between regions objectively exists. In the process of promoting regional digital development, different measures should be taken for different regions. Economically developed regions should be encouraged to take the lead in carrying out digital integration, establish channels for the flow of digital elements in spatial scope, and promote the efficient development of the digital economy. On this basis, high-quality digital production factors can be delivered to economically underdeveloped regions through inter-regional circulation channels, releasing the digital potential of industries in the central and western regions, thereby providing new impetus for China's economic growth. Second, enhance the application of digital technologies in non-digital high-tech manufacturing sectors and their deep integration in productive service industries. At present, there is still a considerable gap between the digitalization level of domestic firms and that of multinational enterprises, especially in the high-tech manufacturing sectors and the production service sectors. During the process of digital transformation, it is necessary to further unleash the potential for digital upgrading of domestic firms in the manufacturing sector. By enhancing the application and integration of digital technologies and strengthening the innovation capabilities at key nodes, the digital gap between domestic firms and multinational enterprises can be narrowed, thereby achieving an overall improvement in the digital economy. Thirdly, the collaborative production between domestic firms and multinational enterprises is creating new impetus for the digital development of the central and western regions. In the future, it is necessary to further strengthen digital technology cooperation with multinational enterprises to lead the digital transformation and development of the domestic industrial chain. In the process of entering the domestic value chain system, multinational enterprises integrate advanced products, management experience, production technology and professional talents into the value chain production through upstream and downstream connections. Domestic firms should fully leverage their demonstration effect and technological spillover effect, gradually enhancing the technological level of key digital departments. Only in this way can they form core competitive advantages in the global digital wave.

Credit authorship contribution statement

Xuefan Guo: Methodology, Data curation, Formal analysis, Writing original draft, Review and editing. **Kunfu Zhu:** Conceptualization, Methodology, Review and editing. **Jiarong Wang:** Data curation, Review & editing.

Declaration of competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Sector classification

TableA.1. Sector classification

Sector Code	Sector Description	Sector Group	Sector Code	Sector Description	Sector Group
S01	Agriculture, forestry and fishing	AGR	S20	Other manufacturing; repair and installation of machinery and equipment	LTI
S02	Coal mining products	MIN	S21	Electricity and heat	EGW

				production and supply	
S03	Oil and gas extraction products	MIN	S22	Gas production and supply	EGW
S04	Metal mining products	MIN	S23	Water production and supply	EGW
S05	Non-metallic minerals and other mining products	MIN	S24	Construction	CON
S06	Food products and tobacco	LTI	S25	Wholesale and retail trade	PSI
S07	Textile	LTI	S26	Transportation and storage	PSI
S08	Textiles, wearing apparel, leather and related products	LTI	S27	Accommodation and food services	LSI
S09	Wood processing products and furniture	LTI	S28	Information transmission, software and information technology services	PSI
S10	Paper products and printing; cultural, educational and sports goods	LTI	S29	Financial and insurance activities	PSI
S11	Coke and refined petroleum products	LTI	S30	Real estate activities	LSI
S12	Chemical products	HTI	S31	Leasing and business services	PSI
S13	Non-metallic mineral products	MTI	S32		PSI
S14	Basic metals	MTI	S33	Scientific research and comprehensive technical services	LSI
S15	Fabricated metal products	MTI	S34	Education	LSI
S16	Machinery and equipment; Instruments and meters	HTI	S35	Human health and social work	LSI
S17	Transport equipment	HTI	S36	Culture, sports and entertainment	LSI
S18	Electrical equipment	HTI	S37	Public administration, social security and social organizations	LSI
S19	Communication equipment, computers and other electronic devices	HTI			

Note: the basis for sector classification comes from OECD and National Bureau of Statistics of China. https://www.oecd.org/sti/inno/researchanddevelopmentstatisticsrds.htm; https://www.stats.gov.cn/sj/tjbz/gjtjbz/. 1) AGR: Agriculture, forestry and fishing; 2) MIN: Mining and quarrying; 3) HTI: High R&D-intensive industries, expressed as high-tech manufacturing sector in the text; 4) MTI: Medium R&D-intensive industries, expressed as medium-tech manufacturing sector in the text; 5) LTI: low-level R&D-intensive industries, expressed as low-tech manufacturing sector in the text; 6) EGW: Electricity, gas, water supply, sewerage, waste and remediation services; 7) CON: Construction; 8) PSI: Productive service industry. 9) LSI: Living service industry

Appendix B. Measurement method of revealed comparative advantage

The Revealed comparative advantage (RCA) index is often used in the field of international trade to measure the competitive advantage of a country's products in the global market and reflect the differences in trade division patterns among different industries. Specifically, the RCA index refers to the proportion of a country's total export value of a certain product in the country's total exports relative to the proportion of the global total export value of that product in the global total exports (Balasa, 1965), providing a quantitative indicator for the traditional theory of comparative advantage. This paper follows the measurement ideas provided by existing studies. Firstly, the calculation method of the RCA index is extended to the regional level. From the perspective of "total value", the comparative advantages of each region-industry in participating in inter-regional trade within the country are measured to represent the upgrading of the industrial structure.

$$\mathrm{RCA\_O_j^{cr}} = \frac{O_j^{cr}}{\sum_j^N O_j^{cr}} \Big/ \frac{\sum_r^G O_j^{cr}}{\sum_r^G \sum_j^N O_j^{cr}} = \frac{O_j^{cr}}{O^{cr}} \Big/ \frac{O_j^c}{O^c} \tag{A.1}$$

which $\mathrm{RCA\_O_j^{cr}}$ represents the RCA index of industry j in region r participating in inter-provincial trade. O_j^{cr} represents the products and services of industry j in region r of China flowing out to other regions within the country. $\sum_j^N O_j^{cr}$ represents the products and services of all industries in region r of China flowing out to other regions within the country. $\sum_r^G O_j^{cr}$ represents the products and services that industry j in all regions of China flow out to other regions of the country, and $\sum_r^G \sum_j^N O_j^{cr}$ represents the products and services that all industries in all regions of China flow out to other regions of the country.

Under the background of economic globalization, the traditional "product trade" has been replaced by "task trade". Ignoring the international production division of labor and the domestic upstream production division of labor will overestimate the export comparative advantage of the industry, while ignoring the domestic downstream division of labor and indirect exports of the country-industry added value will underestimate the export comparative advantage of the industry, which may lead to a strategic misjudgment of "reversal" of advantages and disadvantages (Su, 2016). Since the traditional total value trade accounting method may bring about "statistical illusions", this paper further defines the comparative advantages of each region - industry participating in inter-provincial trade under the production division of the domestic value chain from the perspective of value added, in order to represent the upgrading of the industrial structure. The calculation formula is shown as (A.2).

$$\mathrm{RCA_{NVC_j}^{cr}} = \frac{\mathrm{V\_NVC_j^{cr}}}{\mathrm{V\_NVC^{cr}}} \Big/ \frac{\mathrm{V\_NVC_j^{c}}}{\mathrm{V\_NVC^{c}}} \tag{A.2}$$

which *V_NVC* represents the trade scale of each region participating in the domestic value chain, and its measurement method draws on the global value chain production decomposition framework proposed by Wang et al. (2017a). Specifically, the value added is decomposed according to different types of value chain activities as:

$$\mathrm{Va}' = \hat{V}B(Y+E) = \hat{V}LY + \hat{V}LA^{IR}BY + \hat{V}LE + \hat{V}LA^{IR}BE$$

$$= \underbrace{\hat{V}LY^{L}}_{V\_R} + \underbrace{\hat{V}LY^{IR}}_{V\_DT} + \underbrace{\hat{V}LA^{IR}BY}_{V\_IR} + \underbrace{\hat{V}LE}_{V\_DE} + \underbrace{\hat{V}LA^{IR}BE}_{V\_IRE} \quad \text{(A.3)}$$

In formula A.3, $\hat{V}LY^{L}$ indicates that the value added originates locally, the upstream and downstream industries are both in the local area, and the final output also meets local demand, which is defined as the local value chain (V_R); VLY^{IR} indicates that the value added originates locally, the upstream and downstream industries are located locally, but the final output meets the demands of other regions within the country. It is defined as the domestic final goods trade value chain (V_DT). $\hat{V}LA^{IR}BY$ indicates that the value added originates locally, the upstream industry is in the local area, but the downstream industry is in other regions of the country, ultimately meeting domestic demand. It is defined as the domestic intermediate goods trade value chain (V_IR). $\hat{V}LE$ indicates that the value added originates locally, the upstream and downstream industries are both locally, but the products are for export, and it is defined as the local export value chain (V_DE); $\hat{V}LA^{IR}BE$ indicates that the value added originates locally, the upstream industry is in the local area, the downstream industry is in other regions of the country, and the products are for export. It is defined as the domestic indirect export value chain (V_IRE). Among them, the value added of the domestic final goods trade value chain (V_DT), the domestic intermediate goods trade value chain (V_IR), and the domestic indirect export value chain (V_IRE) are implicit in the inter-provincial outbound trade activities in the region and participate in the competition among domestic regions. They can be defined as domestic value chain (V_NVC).

$$\text{V\_NVC} = \hat{V}LY^{IR} + \hat{V}LA^{IR}BY + \hat{V}LA^{IR}BE = \hat{V}L(A^{IR}X + Y^{IR}) \quad \text{（A.4）}$$