How does the digital economy promote the development of the dual circulation pattern? -An analysis based on the input-output table of the digital economy

Abstract: This paper provides empirical evidence from China and uses China 's input-output table data to study the impact of digital economy development on the dual circulation (economic domestic circulation and international circulation) and its transmission mechanism. The research contents of this paper include: Firstly, this paper compiles non-competitive input-output tables considering the digital economy sector in China from 2007 to 2020, and on this basis, calculates the total amount of digital economy, analyzes the dependence relationship between traditional economy and digital economy, and measures the contribution level of digital economy to the whole economy. Secondly, based on the perspective of supply and demand, the matrix analysis method is used to decompose GDP into domestic and international circulation, and the measurement index of domestic and international circulation participation is constructed. Thirdly, through the analysis of industry heterogeneity, the impact of digital economy on domestic and international economic circulation is studied. Fourthly, based on the SDA model, the driving factors are comprehensively analyzed. The results show that in terms of quantitative relationship, China 's position as the main body of the domestic economic circulation is basically established. The contribution rate of domestic economic circulation to GDP increased from 78.95 % in 2007 to 88.91 % in 2020. Consumption and initial investment are the primary driving forces to drive or promote China 's economic growth. The average annual growth rate of GDP created by the digital economy sector is 10.31 %, which is higher than the GDP growth rate in the same period, and has become an important driving force for economic growth ; the participation of the digital economy sector in the domestic and international circulations is similar to that of traditional industries, but the dependence on the international circulation is higher than that of traditional industries, more dependent on exports and intermediate inputs of imports, and the contribution rate to the GDP of the international economic circulation is always at a high level. From the decomposition results, the international economic circulation is mainly influenced by the effect of change in the coefficient of intermediate inputs of imports, the effect of change in the production structure and the effect of change in the coefficient of value added. This paper has the following innovations: firstly, from a theoretical perspective, this paper uses the input-output analysis method to comprehensively examine the development level of the digital economy and its impact on the economic circulation, and provides a complete framework for studying the quantitative relationship between the digital economy and the domestic and international economic circulations. Secondly, this paper constructs the measurement index of domestic and international economic circulation, and provides a complete quantitative analysis. Its connotation is consistent with the structural analysis of domestic and international economic circulation at the theoretical level, and achieves the organic unity of theory and practice. Thirdly, this paper manually compiled China 's non-competitive input-output table of digital economy from 2002 to 2020, and the selected data are relatively new, which has important research value for the current measurement of China 's domestic and international economic circulation level. Finally, this paper analyzes the mechanism and driving factors of how the digital economy affects the domestic and international economic circulation, and supplements the shortcomings of the existing literature.

Keywords: digital economy; dual-circulation development pattern; input-output model
JEL Classification:C67-F43-O24

1. Introduction

As big data, the Internet of Things (IoT), artificial intelligence (AI), blockchain, and other digital technologies have rapidly developed, the digital economy has become a “new engine” for national economic growth (Corbett, 2018; Singhal et al., 2018). Currently, global data flow and the wealth generated by digital economic activities are growing rapidly, with the digital economy accounting for 4.5% to 15.5% of the world's Gross Domestic Product (GDP), and this share is expected to continue expanding (UNCTAD, 2019, 2021). As a new form of economy, the digital economy refers to a series of economic activities that use digital knowledge and information as key production factors, employ modern information networks as an important carrier, and leverage the effective use of Information and Communication Technology (ICT) to drive efficiency improvements and economic structural optimization. The digital economy is a manifestation of the industrialization and marketization of the information technology revolution. It constantly breaks the closed manufacturing process and accelerates the integration and penetration into various fields. Due to the penetration effect of the digital economy and its reshaping of the division of labor in the global industrial chain, the development of the digital economy can promote the rapid flow of various resource factors, the accelerated integration of various market players, cross-border development, break the time and space constraints, and extend the industrial chain. This helps accelerate the construction of China’s new “dual circulation” development pattern.[1]

The dual circulation development pattern is a new economic development model proposed by the Chinese government. It is aimed at achieving high-quality economic development, building a new open economic system, and constructing a modern economic system through the main framework of domestic circulation and mutual promotion of domestic and international circulations. Besides, the dual circulation development pattern also helps promote the liberalization and facilitation of global trade and investment, and advance more balanced, inclusive, and sustainable economic globalization. For emerging market countries, the dual circulation development pattern is also of great importance. By learning from China's experiences and practices in building domestic circulation, developing digital economy, and promoting domestic and international circulations, these countries can optimize their industrial structure, improve their economic level and competitiveness, and achieve economic transformation and sustainable development. This also provides more opportunities for these countries to participate in the process of globalization. Therefore, one of the implications of this paper is to provide lessons and insights for developing countries by studying the changing pattern of dual circulation development in China. The key concept of the dual circulation development pattern is “economic circulation”. This concept can be traced back to Francois Quesnay's circular flow in the economy (Quesnay and Reichlin, 2008). Marx expounded on the economic circulation from the perspective of capital circulation, which has become the theoretical support for China’s dual circulation. From a geographical perspective, economic circulation is divided into international and domestic economic circulation. The theory of international economic circulation can be traced back to Adam Smith's theory of division of labor (Smith, 2010), David Ricardo's theory of comparative advantage (Ricardo, 1891), John Stuart Mill's

[1] First introduced at a politburo meeting in May, the new ‘dual circulation’ strategy has immediately become a buzzword and been widely discussed both home and abroad. The strategy envisions a new economic development mode by relying less on global integration and expanding domestic reliance. In the face of rising global uncertainties associated with an increasingly hostile external environment, the new dual circulation strategy indicates China’s attempt to establish a new paradigm that attaches balanced importance to both internationalization and self-sufficiency to cope with external vulnerabilities.

theory of international value (Mill J S, 2012), and other views. The mercantilist school's advocacy of protecting the domestic market, Lister's theory of stages of national development, and Keynes' theory of effective demand (Keynes, 2009) all provide theoretical references for the domestic economic cycle.

Existing literature focuses on the interpretation and demonstration of policy documents based on the different schools of thought. Scholars interpret the core content or basic logic of the dual circulation development pattern as promoting high-quality industrialization strategy (Huang and Ni, 2021a), coordinating development and security (Gao,2021), achieving industrial chain modernization through domestic demand and global resources (Liu, 2020), mutual promotion of domestic reproduction and external demand (Hong, 2021). Existing research has profound significance in explaining the real meaning of the dual circulation development pattern and demonstrating the necessity of China's economy to rely on domestic circulation as the main body and promote the mutual promotion of domestic and international circulation. However, these studies have not analyzed the structure of dual circulation and have insufficient discussions on the coordination between domestic and international circulation. Besides, the measurement of dual-circulation has been the focus of recent research, with studies measuring the domestic and international dual circulation from the perspective of local economies (Li and Liu, 2022; Zhang and Fang, 2022; Zhao and Zhang, 2022) and the overall Chinese economy (Huang and Ni, 2021a; Su and Liang, 2021). Measurement models have been constructed based on coupling theory (Zhao and Zhang, 2022), econometric theory (Dai et al., 2022; Du and Hong, 2021), and input-output theory (Chen et al., 2022; Ding and Zhang, 2022; Chen, 2022). Currently, research on the construction of a new development pattern is mainly qualitative analysis, and the measurement of the domestic and international dual circulation is still in the exploratory stage. The above studies have laid a good foundation for the quantitative analysis of the domestic and international dual circulation. However, there are some shortcomings in related research: in terms of the scientificity of measurement indicators, using reference to foreign trade dependence as a measure of the degree of economic growth associated with foreign resources and markets may result in double counting of the same processed goods in imports and exports, leading to an overestimation of the economic dependence on foreign countries. (Liu et al., 2019; Johnson & Noguera, 2012; Li and Xu, 2013; Liu et al., 2017; Xie et al., 2020). In terms of research data selection, the main research time span is from 2000 to 2014, and the timeliness of the data is slightly insufficient.

Research on the impact of the digital economy on the dual-circulation development pattern is closely related to two main branches of literature. One examines the impact of digital economic development on domestic industry linkages, while the other explores the effects of the digital economy on the global industrial chain. Regarding industry linkages, the digital economy affects changes in the industrial structure through changes in production costs, prices, and resource allocation. Specifically, digital technology complements other production, management, and other technological elements to restructure and integrate various factors of production, leading to improved production patterns and industrial linkage effects. This can promote optimization of the production sector structure(Goldfarb and Tucker, 2019; Heo and Lee, 2019). Additionally, the application of big data, cloud computing, blockchain, and artificial intelligence helps companies improve customer management, predict market demand, and adjust factor allocation from the supply side. It also enhances data sharing capabilities between upstream and downstream companies, improving the traceability of the entire industry chain (Aghion et al., 2017; Gereffi et al., 2005;

Sturgeon, 2001).Regarding the global industrial chain, while the manufacturing global value chain has slowed down and stalled, the digital economy has increased the degree of global division of complex technical products, promoting the formation of a global innovation chain. Specifically, the characteristics of faster digital technology upgrades, increased system complexity, rising R&D costs, and shrinking product cycles make innovation and production more difficult alone. This objectively requires global division of labor and cooperation. Enterprises with higher productivity tend to procure from multiple countries to reduce total costs (Antràs et al., 2017). Meanwhile, digital technology provides conditions for shared R&D and new ways of collaborative innovation, driving the multi-layered and diversified development of the global innovation network. More and more parts of technological capabilities cross national boundaries to become global systems, integrated into the global industrial and innovation chains, which is significant for all countries around the world (Gereffi & Fernandez-Stark, 2018; Keller & Yeaple, 2013). In conclusion, the above research provides profound insights into the impact of the digital economy. However, the discussion on the mechanisms of the digital economy's impact on the dual-circulation development pattern seems scattered.

Based on this, this paper has the following innovations: firstly, from a theoretical perspective, we apply the input-output analysis method to comprehensively examine the development level of the digital economy and its impact on the economic circulation, providing a complete framework for studying the quantitative relationship between the digital economy and the domestic and international circulation. Secondly, the measurement indexes of dual circulation are constructed and a complete quantitative analysis is provided. Its connotation is consistent with the structural analysis of domestic and international economic circulation at the theoretical level, achieving the organic unification of theory and practice. Finally, based on the SDA structural decomposition analysis method, the mechanism, and drivers of how the digital economy affects the domestic and international economic circulation are studied, which complements the existing literature.

2. Data Description

2.1. The division of digital economy sector

In June 2021, the National Bureau of Statistics of China released the "Statistical Classification of Digital Economy and its Core Industries (2021)". Based on "digital industrialization" and "industrial digitalization", the basic scope of the digital economy was determined, and the digital economy industry was divided into five major categories: (1) digital product manufacturing; (2) digital product services;(3) digital technology applications;(4) digital factor-driven industries;(5) digital efficiency improvement industries. [2]This classification standard is guided by existing policy documents, fully draws on international experience, and is based on the current statistical system and methods, with the characteristics of wide coverage, high international comparability, and strong operability. It provides a foundation for the calculation of the digital economy and its core industries, and has become an important statistical standard in China's digital economy field. In this paper, the digital economy is defined and classified using this digital economy classification standard.

[2] The first four categories correspond to the digital industrialization part of the core digital economy industries, mainly including computer, communication and other electronic equipment manufacturing, telecommunications, broadcasting, television and satellite transmission services, internet and related services, software, and information technology services, etc., which are the foundation of the development of the digital economy. The fifth category, digital efficiency improvement industries, corresponds to the industrial digitalization part, referring to the output increase and efficiency improvement brought to traditional industries by applying digital technology and data resources, and is the integration of digital technology and the real economy.

We conduct a study on China's digital economy using the Input-Output Table (IOT) data from 2007 to 2020. Each department in the IOT corresponds to one or more middle categories in the Chinese National Economic Industry Classification, which includes both digital and non-digital industries. Therefore, it is necessary to disaggregate and reorganize the IOT departments according to the digital economy types and their corresponding proportions in each department. The adjusted IOT is then used for analysis. The basic methodology for identifying and disaggregating the product sectors is as follows:

(1) Clarify the correspondence between the Input-Output sectors and the subcategories and sub-subcategories of the National Economic Industry Classification (GB/T4754—2017).

(2) Organize the Input-Output Table for each year according to the National Economic Industry Classification Standard (GB/T4754—2017), and disaggregate or merge the differing sectors to ensure comparability of the number of industries and calculation results. We adjusted the Input-Output Table for each year to 41 product sectors.[3]

(3) Determine the digital economic type corresponding to the sub-subcategories of the National Economic Industry Classification according to the Statistical Classification of Digital Economy and Its Core Industries (2021), and summarize the digital economic types of the subcategories into 41 product sectors, obtaining the digital economic types and corresponding proportions of each sector, i.e., the digital economic adjustment coefficients for each sector.

(4) Disaggregate the product sectors containing multiple digital economic types based on the digital economic adjustment coefficients, obtaining data for departments with different digital economic types in the same product sector.

(5) After compiling the competitive digital economy Input-Output Table, assume the Input-Output Table is adjusted to non-competitive Input-Output Table based on the import proportion.

After identifying the digital economic type of the 41 sectors in the Input-Output Table using the Statistical Classification of Digital Economy and Its Core Industries (2021), two sectors have a clear and unique digital economic type, and 14 sectors correspond to two digital economic types. These sectors need to be disaggregated using digital economic adjustment coefficients, resulting in a total of 55 sectors divided into five types: Type I for digital product manufacturing, Type II for digital product services, Type III for digital technology applications, Type IV for digital factor-driven sectors, and Type V for other sectors regarded as traditional sectors. Some product sectors have been disaggregated into multiple digital economic types, such as the chemical product sector disaggregated into chemical products (Type I) and chemical products (Type V), representing the part belonging to the digital product manufacturing sector and the part belonging to the digital efficiency improvement sector (that means traditional sector), respectively. Table 1 shows the departments included in each digital economic type.

Table 1: Product departments included in each digital economy type

Digital Economy Type	Departments
Digital Product Manufacturing (7 sectors)	Paper Printing and Educational, Sports, and Cultural Supplies (I), Chemical Products (I), General Equipment (I), Special Equipment (I), Electrical Machinery and Equipment (I), Communications Equipment, Computers, and Other Electronic Equipment, Instruments and Apparatus (I)

[3] Appendix Table A.2 gives the adjusted input-output table sectoral classification.

Digital Product Services (3 sectors)	Wholesale and Retail (II), Leasing and Business Services (II), Residential Services, Repair and Other Services (II)
Digital Technology Application (2 sectors)	Information Transmission, Software and Information Technology Services (III), Comprehensive Technical Services (III)
Digital Factor-driven (4 sectors)	Construction (IV), Finance (IV), Research and Experimental Development (IV), Culture, Sports and Entertainment (IV)
Digital Efficiency Improvement (39 sectors)	Other Traditional Sectors

Note: According to the "Statistical Classification of Digital Economy and Its Core Industries (2021)", wholesale industry includes both digital product services and digital technology application industries; Internet-related services exist in both digital technology application and digital element-driven categories; In line with the principle of more merging and less splitting, all digital economic core industries in wholesale industry are classified into digital product services here; At the same time, Internet-related services are classified into digital technology application industry.

2.2. Digital Economy Adjustment Coefficient

When identifying and classifying industries, some of them only have a portion of their content related to the digital economy. To address this issue, this paper introduces the "digital economy adjustment coefficient" to separate the digital economy portion from the department or industry. The digital economy adjustment coefficient refers to the ratio of the value added of the digital economy to the total value added of the industry, as shown in formula (1).

$$\textit{Digital economy adjustment coefficient} = \frac{\textit{The value added of the digital economy in the industry.}}{\textit{The total value added of the industry.}} \quad (1)$$

Meanwhile, the value added rate of the industry refers to the ratio of the value added of each industry in the national economy to the total output, as shown in formula (2).

$$\textit{The value added rate of the industry} = \frac{\textit{The value added of the industry}}{\textit{The total output of the industry}} \quad (2)$$

Drawing on the measurement method proposed by Barefoot et al. (2018), this article assumes that the proportion of intermediate consumption of the digital economy portion in the industry to the total output of the digital economy is the same as the proportion of intermediate consumption in the industry to the total output of the industry. In other words, the value added rate of the digital economy is the same as the value added rate of the industry in which it belongs, as shown in formula (3).

$$\frac{\textit{The value added of the digital economy in the industry}}{\textit{The total output of the digital economy in the industry}} = \frac{\textit{The total value added of the industry}}{\textit{The total output of the industry}} \quad (3)$$

By changing formula (3), we can get

$$\textit{Digital economy adjustment coefficient} = \frac{\textit{The total output of the digital economy in the industry}}{\textit{The total output of the industry}} \quad (4)$$

As can be seen, the digital economy adjustment coefficient is both the ratio of the added value of the digital economy part to the total added value of the industry and the ratio of the total output of the digital economy part to the total output of the industry. When splitting the product department according to the type of digital economy, it is only necessary to know the proportion of the total output of each type of digital economy in the sector. However, since the digital economy related industries are specific to the sub-categories of the national economic industries, the existing statistical data on total output cannot meet the accuracy requirements for calculating the digital economy adjustment coefficient. Therefore, we use the revenue data of each industry in the "China Statistical Yearbook" "China Economic Census Yearbook" and "China Industrial Statistics Yearbook" and assumes that the revenue of each sub-industry in a certain industry is the same as the proportion of the total output of that sub-industry to the total output of the industry, called the digital economy separation coefficient (the digital economy separation coefficient for each year is shown in Appendix Table A.2). From this, the digital economy input-output table for each year can be compiled. Following the existing literature, this paper first uses the digital economy input-output table to calculate the added value of China's digital economy core sectors. The added value and structure of China's digital economy core sectors are shown in Table 2. The results show that from 2007 to 2020, the added value of China's digital economy core sectors grew rapidly, from 1.75 trillion yuan in 2007 to 7.406 trillion yuan in 2020, with an average annual growth rate of 12%, far higher than the GDP growth rate of 7.49% during the same period. The proportion of the digital economy core sectors in GDP increased from 6.58% to 8.92%, indicating that digital industrialization has a significant driving effect on economic growth. From the perspective of the composition of the digital economy core sectors, although the total amount of each part has increased significantly, the distribution structure has shifted from being dominated by digital product manufacturing to being dominated by digital technology application. The proportion of digital products serving digital factor-driven has also increased, indicating that China's digital industrialization has a good application market.[4]

Table 2: Value Added and Structure of Core Digital Economy Sectors

Year	Value Added (100 million yuan)	GDP Share (%)	Digital Product Manufacturing (%)	Digital Product Services (%)	Digital Technology Applications (%)	Digital Factor Driven (%)
2007	17516.72	6.58	46.41	5.23	34.98	13.38
2010	24171.63	6.25	42.44	6.21	36.03	15.32
2012	23923.93	6.38	44.17	4.73	35.26	15.84
2015	48617.30	7.77	38.11	7.46	35.46	18.97
2017	59927.28	8.39	29.49	12.36	43.36	14.78
2018	64405.01	8.30	26.84	10.36	45.77	17.03
2020	74060.94	8.92	23.43	8.71	50.02	17.84

Note: The scale of the digital economy is adjusted for price using the producer price index of products and the price index of related services in the CPI. The proportion of the digital economy to GDP and its composition are calculated at current prices for each year.

3. Models

3.1. GDP decomposition based on demand and supply perspectives

Existing literature usually has two interpretations of the dual circulation concept in the national economy. One approach, from the perspective of national economic accounting, understands domestic circulation as domestic demand, and accordingly, understands international circulation as foreign demand (Xu, 2020). The other approach, from the perspective of product markets and

[4] Since the digital industrialization considered in this paper not only includes the ICT sector but also separates the digital economy in traditional sectors, the results are higher than those of Xu Xianchun et al. but lower than those of the China Academy of Information and Communications Technology, which considers digitalization of industries. This paper has a certain degree of reliability in terms of data consistency with Xu Yingmei et al. (2020) in defining the scope of China's digital economy core sectors, with minor differences in results (the proportion of China's digital economy core sectors to GDP in 2018 is 9.8% in their calculation).

resource supply, understands domestic circulation as providing products, services and using domestic production factors for the domestic market, and international circulation as providing products, services and using foreign production factors for foreign markets (Tang et al., 2020). Therefore, input-output tables can reflect the degree of participation in domestic and international circulation from both demand and supply perspectives. In the input-output table, the total output demand is driven by domestic intermediate demand, foreign intermediate demand, domestic consumption, domestic investment, foreign consumption, and foreign investment, etc., while the total output supply is pushed by domestic intermediate inputs, foreign intermediate inputs and their domestic value-added, etc. Using the relationships between these quantities in the input-output table, the Gross Domestic Product (GDP) can be decomposed into domestic circulation GDP and international circulation GDP through matrix operations, thus obtaining the contribution rates of domestic and international circulation to the GDP, and measuring the dual circulation of the economy. The domestic circulation GDP can be represented by the GDP driven or pushed by domestic investment, exports, and initial input, while the international circulation GDP can be represented by the GDP driven or pushed by intermediate inputs in exports and imports. Specifically:

The row balance equation can be obtained from the input-output table:

$$\boldsymbol{A}^d \boldsymbol{X} + \boldsymbol{C}^d + \boldsymbol{I}^d + \boldsymbol{Ex} = \boldsymbol{X} \tag{5}$$

In equation (5), $\boldsymbol{A}^d$ represents the matrix of direct consumption coefficients, $\boldsymbol{X}$ represents the total output vector. $\boldsymbol{A}^d \boldsymbol{X}$, $\boldsymbol{C}^d$, and $\boldsymbol{I}^d$ represent the domestic intermediate demand, domestic consumption, and domestic investment, respectively, while $\boldsymbol{Ex}$ represents exports. Let the identity matrix be $\boldsymbol{E}$, then equation (5) gives:

$$\boldsymbol{X} = (\boldsymbol{E} - \boldsymbol{A}^d)^{-1}[\boldsymbol{C}^d + \boldsymbol{I}^d + \boldsymbol{Ex}] \tag{6}$$

In equation (6), $(\boldsymbol{E} - \boldsymbol{A}^d)^{-1}$ is the output matrix of expenditure demand. Let $\boldsymbol{V}$ denote the value added column vector; let $\boldsymbol{A}_v$ be the 55×55 diagonal matrix, the elements on the diagonal represent the proportion of value added to total inputs in the industry, i.e., the value added rate. It means the matrix of conversion from output to value added, i.e., $\boldsymbol{V} = \boldsymbol{A}_v \boldsymbol{X}$. Substituting equation (6) into it yields the value added decomposition in terms of demand:

$$\boldsymbol{V} = \boldsymbol{A}_v(\boldsymbol{E} - \boldsymbol{A}^d)^{-1}[\boldsymbol{C}^d + \boldsymbol{I}^d + \boldsymbol{Ex}] = \boldsymbol{A}_v(\boldsymbol{E} - \boldsymbol{A}^d)^{-1}\boldsymbol{C}^d + \boldsymbol{A}_v(\boldsymbol{E} - \boldsymbol{A}^d)^{-1}\boldsymbol{I}^d + \boldsymbol{A}_v(\boldsymbol{E} - \boldsymbol{A}^d)^{-1}\boldsymbol{Ex} \tag{7}$$

In equation (7), from the demand perspective, domestic value added can be decomposed into three components. First, domestic consumption-driven GDP $\boldsymbol{A}_v(\boldsymbol{E} - \boldsymbol{A}^d)^{-1}\boldsymbol{C}^d$; second, domestic investment-driven GDP as $\boldsymbol{A}_v(\boldsymbol{E} - \boldsymbol{A}^d)^{-1}\boldsymbol{I}^d$; third, export-driven GDP as $\boldsymbol{A}_v(\boldsymbol{E} - \boldsymbol{A}^d)^{-1}\boldsymbol{Ex}$.

Let $\boldsymbol{M}$ be the vector of intermediate input columns of imports in each industry. Then the equilibrium equation of total inputs considering imports can be expressed as:

$$\boldsymbol{X'A}^{d'} + \boldsymbol{M'} + \boldsymbol{V'} = \boldsymbol{X'} \tag{8}$$

From equation (8), we can obtain:

$$\boldsymbol{X} = (\boldsymbol{E} - \boldsymbol{A}^d)^{-1}(\boldsymbol{M} + \boldsymbol{V}) = (\boldsymbol{E} - \boldsymbol{A}^d)^{-1}\boldsymbol{M} + (\boldsymbol{E} - \boldsymbol{A}^d)^{-1}\boldsymbol{V} \tag{9}$$

From equation (9), total input consists of two components: one is the total input due to initial input $(\boldsymbol{E} - \boldsymbol{A}^d)^{-1}\boldsymbol{V}$; the other is the total input due to intermediate input of imported goods $(\boldsymbol{E} - \boldsymbol{A}^d)^{-1}\boldsymbol{M}$. Substituting equation (9) into $\boldsymbol{V} = \boldsymbol{A}_v \boldsymbol{X}$ gives a decomposition of value added based on the supply perspective:

$$\boldsymbol{V} = \boldsymbol{A}_v \boldsymbol{X} = \boldsymbol{A}_v(\boldsymbol{E} - \boldsymbol{A}^{d'})^{-1}\boldsymbol{V} + \boldsymbol{A}_v(\boldsymbol{E} - \boldsymbol{A}^{d'})^{-1}\boldsymbol{M} \tag{10}$$

From equation (10), the GDP based on the supply perspective can be divided into two components: first, the GDP due to initial inputs $\boldsymbol{A}_v(\boldsymbol{E} - \boldsymbol{A}^d)^{-1}\boldsymbol{V}$, which can characterize the domestic economic circulation from the input supply side; and second, the GDP due to foreign intermediate inputs $\boldsymbol{A}_v(\boldsymbol{E} - \boldsymbol{A}^d)^{-1}\boldsymbol{M}$, which can characterize the international economic circulation from the input supply side.

3.2. Dual circulation contribution rate by considering supply and demand perspective

Equation (7) decomposes GDP from the demand perspective, and equation (10) decomposes GDP from the supply perspective, and the two sides of the equation are summed separately as shown in equation (11).

$$\begin{aligned}\boldsymbol{2V} &= \boldsymbol{A}_v(\boldsymbol{E}-\boldsymbol{A}^d)^{-1}\boldsymbol{C}^d + \boldsymbol{A}_v(\boldsymbol{E}-\boldsymbol{A}^d)^{-1}\boldsymbol{I}^d + \boldsymbol{A}_v(\boldsymbol{E}-\boldsymbol{A}^d)^{-1}\boldsymbol{Ex} + \boldsymbol{A}_v(\boldsymbol{E}-\boldsymbol{A}^d)^{-1}\boldsymbol{V} + \boldsymbol{A}_v(\boldsymbol{E}-\boldsymbol{A}^d)^{-1}\boldsymbol{M} \\ &= \left[\boldsymbol{A}_v\boldsymbol{B}(\boldsymbol{C}^d+\boldsymbol{I}^d)+\boldsymbol{A}_v\boldsymbol{BV}\right]+\left[\boldsymbol{A}_v\boldsymbol{BEx}+\boldsymbol{A}_v\boldsymbol{BM}\right]\end{aligned} \quad (11)$$

In equation (11), $\boldsymbol{B}=(\boldsymbol{E}-\boldsymbol{A}^d)^{-1}$, equation (11) sums up the GDP from the demand and supply perspectives and can be regarded as twice the GDP in quantitative terms. $\boldsymbol{A}_v\boldsymbol{B}(\boldsymbol{C}^d+\boldsymbol{I}^d)+\boldsymbol{A}_v\boldsymbol{BV}$ denotes the total GDP pulled or driven by domestic consumption, domestic investment, and domestic initial inputs, i.e., the total value of GDP created through the internal circulation of the economy; $\boldsymbol{A}_v\boldsymbol{BEx}+\boldsymbol{A}_v\boldsymbol{BM}$ denotes the total GDP pulled or driven by exports and foreign intermediate inputs, i.e., the total GDP created through the external circulation of the economy gross value. Thus, the contribution of the domestic economic cycle to GDP can be expressed as:

$$\gamma_d = [\mu'\boldsymbol{A}_v\boldsymbol{B}(\boldsymbol{C}^d+\boldsymbol{I}^d)+\mu'\boldsymbol{A}_v\boldsymbol{BV}]/2\mu'\boldsymbol{V} \quad (12)$$

In equation (12), μ represents a column vector with all elements of 1. The contribution rate of foreign economic circulation to GDP can be expressed as:

$$\gamma_f = [\mu'\boldsymbol{A}_v\boldsymbol{BEx}+\mu'\boldsymbol{A}_v\boldsymbol{BM}]/2\mu'\boldsymbol{V} \quad (13)$$

The contribution rate of the domestic circulation of the industry to the GDP of the sector i can be expressed as:

$$\gamma_{di} = [\mu'\boldsymbol{A}_v\boldsymbol{B}(\boldsymbol{C}_i^d+\boldsymbol{I}_i^d)+\mu'\boldsymbol{A}_v\boldsymbol{BV}_i]/2\mu'\boldsymbol{V}_i \quad (14)$$

The contribution rate of the foreign circulation of the industry to the GDP of the sector i can be expressed as:

$$\gamma_{fi} = [\mu'\boldsymbol{A}_v\boldsymbol{BEx}_i+\boldsymbol{E}_i'\boldsymbol{A}_v\boldsymbol{BM}_i]/2\mu'\boldsymbol{V}_i \quad (15)$$

The contribution rate of domestic circulation in sector i to the national economy's domestic circulation GDP is

$$\gamma_{di} = [\mu'\boldsymbol{A}_v\boldsymbol{B}(\boldsymbol{C}_i^d+\boldsymbol{I}_i^d)+\mu'\boldsymbol{A}_v\boldsymbol{BV}_i^d]/[\mu'\boldsymbol{A}_v\boldsymbol{B}(\boldsymbol{C}^d+\boldsymbol{I}^d)+\mu'\boldsymbol{A}_v\boldsymbol{BV}] \quad (16)$$

The contribution rate of foreign circulation in sector i to the national economy's foreign circulation GDP is:

$$\gamma_{fi} = [\mu'\boldsymbol{A}_v\boldsymbol{BEx}_i+\mu'\boldsymbol{A}_v\boldsymbol{BM}_i]/[\mu'\boldsymbol{A}_v\boldsymbol{BEx}+\mu'\boldsymbol{A}_v\boldsymbol{BM}] \quad (17)$$

In equation (13)-(17), $\boldsymbol{C}_i^d$ 、$\boldsymbol{I}_i^d$ 、$\boldsymbol{V}_i$ 、$\boldsymbol{Ex}_i$ 、$\boldsymbol{M}_i$ represent the column vectors with all elements zero except for the sector element which is the corresponding value, e.g. $\boldsymbol{C}_i^d=\left[0,\cdots,C_i^d,\cdots,0\right]^{\mathrm{T}}$.

4. Empirical analysis

4.1. Decomposition and Contribution of China's GDP

GDP decomposition based on the demand perspective. Based on the non-competitive input-output table, the contribution of consumption, investment, and exports to China's Gross Domestic Product (GDP) from the demand side was calculated using Equation (9). Table 3 shows the contribution rates of consumption, investment, and exports from 2007 to 2020. Specifically, GDP driven by consumption increased from 11097.83 billion yuan in 2007 to 341543.61 billion yuan in 2020, with an average annual growth rate of 9.03%, making it the main contributor to economic growth. Its contribution rate fluctuated from 42.05% in 2007 to 49.29% in 2020. GDP driven by investment increased from 81993.70 billion yuan in 2007 to 250259.12 billion yuan in 2020, with an average annual growth rate of 8.96%. Its growth trend and proportion changes were similar to those of consumption-driven GDP, but its total amount and proportion were smaller, with an average contribution rate of about 36.39%. GDP driven by exports was smaller than that of investment and consumption in terms of growth rate and contribution rate. Its average growth rate during the study period was 7.70%, and its contribution rate to GDP decreased from 26.88% in 2007 to 14.59% in 2020.

Table 3 China's demand-side GDP and structure from 2007 to 2020:

Year	Consumption-driven GDP	Investment-driven GDP	Export-driven GDP	Consumption contribution rate (%)	Investment contribution rate (%)	Export contribution rate (%)
2007	110977.83	81993.70	70953.42	42.05	31.07	26.88
2008	112713.47	106662.51	68954.58	39.09	36.99	23.92
2009	128109.83	107266.73	74468.86	41.35	34.62	24.03
2010	146272.03	127794.76	74578.32	41.95	36.65	21.39
2011	165766.35	130697.48	77690.07	44.30	34.93	20.76
2012	185105.63	154464.33	81199.68	43.99	36.71	19.30
2013	202251.61	156785.14	77850.11	46.29	35.89	17.82
2014	212874.70	171190.18	89328.75	44.97	36.16	18.87
2015	242094.24	189546.61	92093.32	46.22	36.19	17.58
2016	260820.58	208993.43	91346.46	46.48	37.24	16.28
2017	281257.76	219866.06	92314.68	47.39	37.05	15.56
2018	303288.62	243616.67	95309.99	47.23	37.93	14.84
2019	323134.55	258092.24	104650.16	47.11	37.63	15.26
2020	341543.61	250259.12	101097.11	49.29	36.12	14.59

Note: GDP is measured in 100 million yuan, with real GDP in 2007 as the base year for each year's calculation. The contribution rates for each year are calculated based on the prices of that year. Data for non-input-output table years are derived from existing data.

GDP decomposition based on the supply perspective. GDP and its contribution rates driven by imported intermediate and initial inputs were calculated from the supply side using Equation (12), as shown in Table 4. Specifically, GDP driven by imported intermediate inputs increased from 40159.25 billion yuan in 2007 to 52519.38 billion yuan in 2020, with an average annual growth rate of 2.09%. Its contribution rate fluctuated from 15.22% in 2007 to 7.58% in 2020. GDP driven by initial inputs increased from 223765.71 billion yuan in 2007 to 640380.47 billion yuan in 2020, with an average annual growth rate of 8.42%. Its total amount and contribution rate were higher than those of imported intermediate inputs.

Table 4 China's supply-side GDP and structure from 2007 to 2020:

	GDP generated by imported intermediate inputs	GDP generated by domestic inputs	Imported intermediate inputs contribution rate %	Domestic inputs contribution rate %
2007	40159.25	223765.71	15.22	84.78
2008	37618.79	250711.78	13.05	86.95
2009	37662.81	272182.61	12.16	87.84
2010	48191.62	300453.50	13.82	86.18
2011	37080.66	337073.25	9.91	90.09
2012	59889.56	360880.08	14.23	85.77
2013	61833.50	375053.37	14.15	85.85
2014	58418.47	414975.17	12.34	87.66
2015	58046.72	465687.45	11.08	88.92
2016	49682.60	511477.88	8.85	91.15
2017	54043.23	539395.27	9.11	90.89
2018	56848.69	585366.58	8.85	91.15
2019	64005.75	621871.20	9.33	90.67

2020	52519.38	640380.47	7.58	92.42

Note: GDP is measured in 100 million yuan, with real GDP in 2007 as the base year for each year's calculation. The contribution rates for each year are calculated based on the prices of that year. Data for non-input-output table years are derived from existing data.

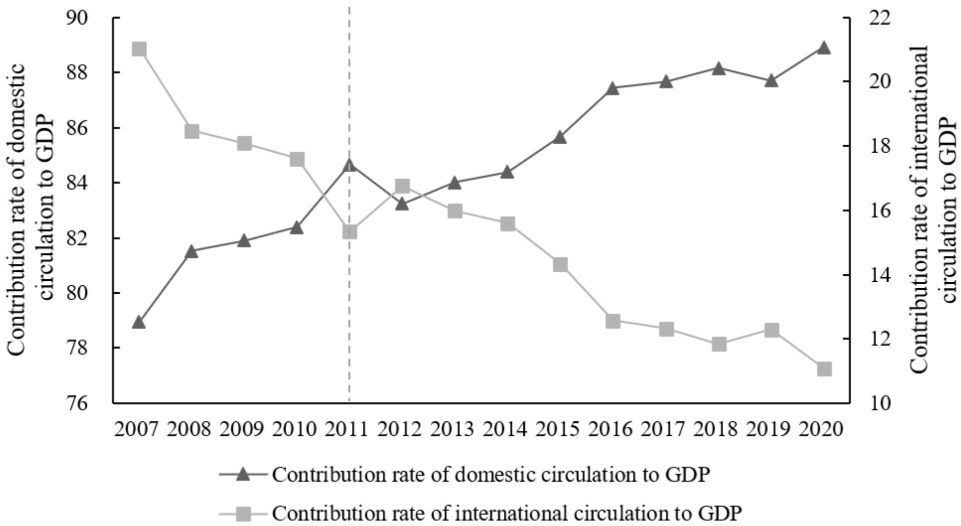

Fig. 1 Contribution rate of domestic and international cycles to GDP (%)

Contribution rate of domestic and international economies to GDP. The contribution of the domestic and international dual circulation to GDP measured in this paper is shown in Figure 1. The contribution rate of the domestic circulation to GDP has fluctuated from 78.95% in 2007 to 88.91% in 2020, while the contribution rate of the international circulation has fluctuated from 21.05% in 2007 to 11.09% in 2020. The difference between the contributions of the domestic and international circulation to GDP has gradually increased since 2011, and during the observation period, China has mainly relied on the domestic circulation with the international circulation as a supplement. Compared with existing literature on the measurement of the domestic and international dual circulation, the results of this study are generally consistent with those of Chen et al. (2022), Huang and Ni (2021), and Chen et al. (2022). Chen et al. (2022) proposed measuring the relative degree of China's participation in domestic and international circulation by measuring China's dependence on domestic and foreign final demand and used WIOD data to calculate the relevant values during the period 2000-2014. Huang and Ni (2021) constructed international and domestic circulation measurement indicators based on the supply side and demand side and a new method for decomposing domestic and international circulation GDP based on the global value chain, and used WIOD data for empirical analysis. Chen (2022) adjusted and merged the global input-output (ICIO) table into non-competitive input-output tables for China and other countries (or regions), decomposed China's GDP, and measured the domestic and international dual circulation from 1995 to 2018. The trend of the contribution rate of the domestic and international dual circulation measured in this paper is consistent with that of the above literature, which is a good supplement to the existing literature. The contribution rates of the domestic circulation to GDP measured in this paper for 2007, 2012, and 2017 were 78.95%, 83.23%, and 87.67%, respectively, while Chen (2022) measured the corresponding contribution rates of the domestic economic circulation to be 81.27%, 85.21%, and 88.56%, with differences of 2.32, 1.98, and 0.89 percentage points, respectively.

Although there are differences between the data due to different data sources, their trends are the same, indicating that the method used in this study is relatively objective.

4.2. Decomposition of GDP in the digital economy sector

GDP decomposition based on the demand perspective. On the output-demand side, the contribution of consumption, investment, and exports to GDP for each industry can be calculated based on the non-competitive input-output table and formula (9), respectively, and the GDP created by each industry can be decomposed. This paper calculates the contribution rates of consumption, investment, and exports to the digital economy sector and traditional industries in China from 2007 to 2020, as shown in Figures 2 and 3, respectively. For the digital economy sector, the contribution rate of investment has rapidly increased from 24.53% in 2007 to 45.00% in 2020, while the proportion of exports has decreased significantly from 44.60% to 20.02%, and the proportion of consumption has remained relatively stable at around 30%. For traditional industries, the contribution rate of consumption remains high, steadily increasing from 42.83% to 50.69%; the proportion of exports has decreased from 25.64% to 14.06%, and the proportion of investment has remained relatively stable at around 30%-35%. The increase in the contribution rate of investment to the digital economy sector indicates the accumulation of digital capital in the economic system, and compared with traditional sectors, the main driving force of the digital economy comes from investment rather than consumption, which also reflects the increasing demand for digital technology capital among various sectors of the economic system. The ultimate products reflect the power of demand, and in a sense, it is the stable and strong growth of demand for digital economic products and services in the development of the national economic system that promotes the development of the digital economy.

This paper further measures the contribution rates of consumption, investment, and exports in different types of digital economy sectors, namely, digital product manufacturing, digital product services, digital technology application, and digital factor-driven sectors, by decomposing the GDP created by these sectors, as shown in Appendix Table A.3. The decomposition of the GDP of these sectors follows a trend similar to that of the overall digital economy but also has industry characteristics. Although the contribution rate of exports in the digital product manufacturing sector has decreased significantly from 73.07% in 2007 to 50.89% in 2020, it is still the primary driving force of its growth, indicating that computer and communication products have become an important force driving export growth. The contribution rate of consumption is higher than that of investment and exports in the digital product services and digital factor-driven sectors, which is similar to the industry characteristics of digital trade and services primarily targeting the consumer sector. The contribution rate of investment in the digital technology application sector has grown rapidly, from 32.81% in 2007 to 53.70% in 2020, indicating the rapid growth in demand for investment in information transmission, software, and information technology services in the economic system.

GDP decomposition based on the supply perspective. The contribution of intermediate and initial input of imported goods to GDP can be calculated according to Equation (12), which measures the proportion of GDP created by each industry's intermediate and initial input of imported goods, i.e., the contribution rate of intermediate and initial input of imported goods for each industry can be calculated, as shown in Figures 4 and 5. It can be seen that for the digital economy sector, the contribution rate of intermediate input of imported goods showed a fluctuating upward trend before gradually declining after 2012, decreasing from 31.37% in 2007 to 15.09% in 2020; the contribution rate of initial input showed a fluctuating downward trend before gradually increasing after 2012, decreasing from 68.63% in 2007 to 15.09% in 2020. For the traditional industries, the contribution rate of intermediate input of imported goods gradually declined from 14.08% in 2007 to 6.84% in 2020; the contribution rate of initial input remained high, rising from 85.92% in 2007 to 93.16% in 2020. Although the digital economy sector and traditional industries have similar trends in the decomposition of GDP on the input supply side, the digital economy sector's dependence on intermediate input of imported goods is consistently higher than that of traditional industries, consistent with the structure on the output demand side, indicating that the digital economy sector has a higher dependence on international circulation.

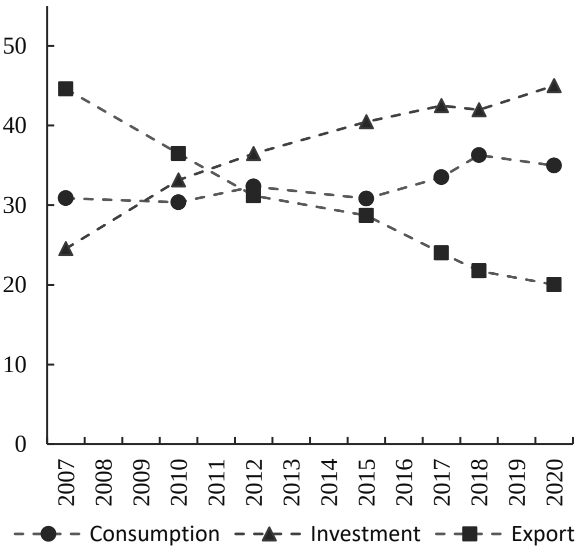

Fig. 2 Decomposition of the GDP of the digital economy sector based on the demand perspective (%)

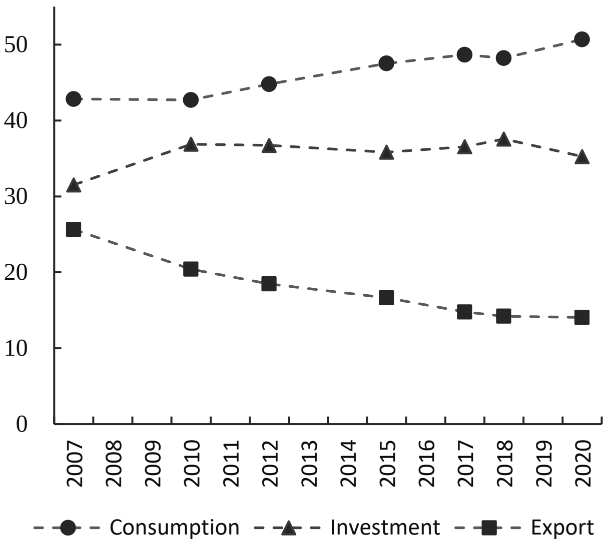

Fig.3 Decomposition of the GDP of traditional sectors based on the demand perspective (%)

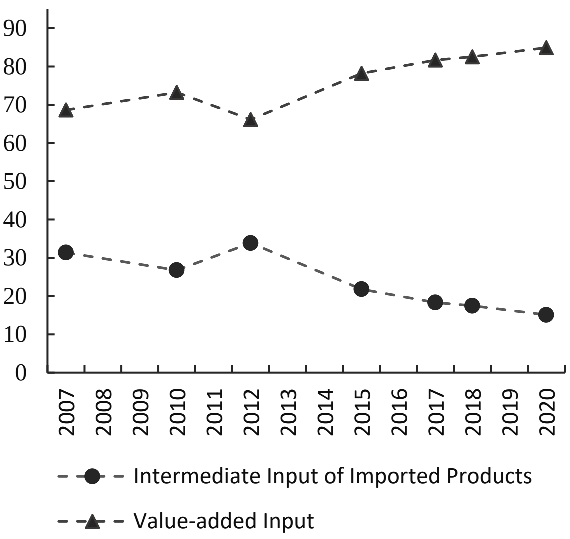

Fig. 4 Decomposition of the GDP of the digital economy sector based on the supply perspective (%)

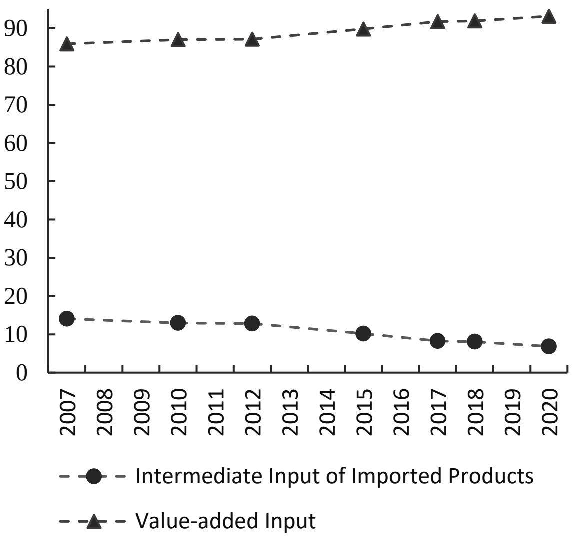

Fig.5 Decomposition of the GDP of traditional sectors based on the supply perspective (%)

This paper further measures the contribution rate of intermediate and initial input of imported goods in the digital product manufacturing, digital product service, digital technology application, and digital factor-driven sectors, as detailed in Appendix Table A.4. Specifically, different types of digital economy sectors have significant differences in the driving force of input supply: the contribution rate of intermediate input of imported goods in the digital product manufacturing sector has always been at a relatively high level, remaining around 50%, combined with the decomposition results of output demand in the digital product manufacturing sector, it can be seen that computer and communication products are not only important forces driving exports but also important forces for importing intermediate input products, indicating that this type of product has a high level of external dependence on both demand and input; the contribution rate of intermediate input of imported goods in the digital product service and digital factor-driven sectors is relatively low, below 5% since 2017, and these two sectors are severely dependent on initial input; the trend of the contribution rate of intermediate input of imported goods in the digital technology application sector is similar to that of the overall digital economy sector, declining from 9.28% in 2007 to 2.16% in 2020.

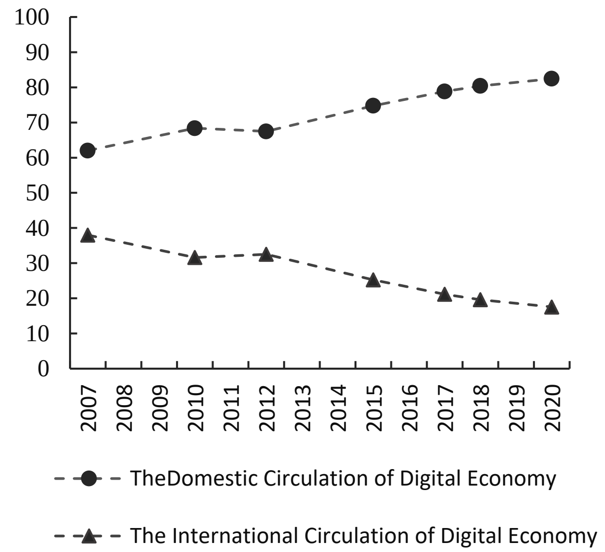

Fig. 6 Domestic and international participation in digital economy (%)

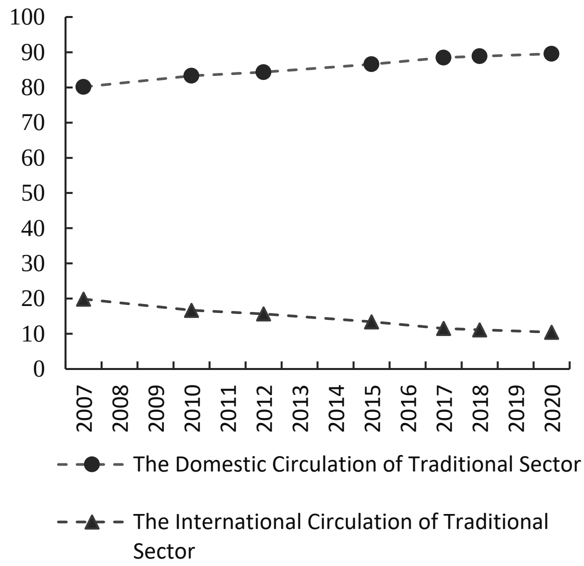

Fig. 7 Domestic and international participation in traditional sectors (%)

The contribution of domestic and international circulation to the GDP of digital economy sector. This paper further measures the contribution of domestic and international circulation to the GDP of the digital economy sector by decomposing it into output demand and input supply levels. Specifically, it examines the total contribution of consumption, investment, and initial input to the digital economy sector, as well as the contribution of intermediate input imports and exports, to represent the degree of participation of the digital economy sector in domestic and international circulation. The results are shown in Figure 6. As shown in the figure, the contribution of domestic circulation to the GDP of the digital economy increased from 62.02% in 2007 to 82.44% in 2020, while the contribution of international circulation decreased from 37.98% in 2007 to 17.56% in 2020. For comparison, this article also reports the contribution of domestic and international circulation to the GDP of traditional industries, as shown in Figure 7. It can be observed that both traditional industries and the digital economy sector have similar trends in domestic and international circulation, with a focus on domestic circulation and international circulation as a supplement. This is consistent with the changes in the contribution of domestic and international circulation to GDP shown in Figure 1, indicating that the development pattern of the domestic large circulation as the main body, and the mutual promotion of domestic and international circulation, is not only reflected in the overall economy and traditional industries but also in emerging industries such as the digital economy sector. However, the digital economy sector relies slightly more on international circulation than traditional industries, especially on exports and imports. This paper also further measures the degree of participation of digital product manufacturing, digital product service, digital technology application, and digital factor-driven departments in domestic and international circulation, as shown in Appendix Table A.5. Specifically, the participation of digital product manufacturing in international circulation is significantly higher than that of other digital economy sectors, with its international circulation reaching as high as 65.29%, and has a higher dependence on exports and intermediate input imports. However, in recent years, the international circulation of digital product manufacturing has significantly decreased, with its participation rate in 2020 being 53.83. Conversely, the level of domestic circulation in digital product manufacturing has increased significantly. The degree of participation in domestic and international circulation for digital product service, digital technology application, and digital factor-driven departments is similar to that of traditional industries, with a focus on domestic circulation and international circulation as a supplement.

4.3. The contribution of the digital economy to domestic and international circulation

Contribution of the digital economy sector to domestic circulation. Based on the analysis of the economic aggregate, we measure the contribution rate of the digital economy sector to the domestic circulation GDP according to formula (18), as shown in Figure 8. Specifically, the contribution rate of the digital economy sector to the domestic circulation GDP increased from 5.16% in 2007 to 8.27% in 2020, which is consistent with its contribution to GDP and the changes in China's economic structure. From the perspective of the digital economy sector, the contribution to the domestic circulation GDP primarily came from the digital technology application sector, followed by the digital product manufacturing sector and the digital factor-driven sector, and finally the digital product service sector. Since 2015, the contribution rate of the digital product manufacturing sector and the digital factor-driven sector to the domestic circulation GDP has declined. In order to further analyze the structural changes that affect the intra-sectoral contribution rate of the digital economy, this study has measured the proportion of GDP pulled or pushed by different types of digital economy sectors through consumption, investment, and initial input, relative to the proportion of GDP pulled by consumption, investment, and initial input at the national level (as shown in Appendix Figures A.1-A.3). From the consumption perspective, the contribution rate of the digital economy sector increased from 4.80% in 2007 to 6.33% in 2020. However, the contribution rate of the digital economy sector to GDP remained higher than its proportion of GDP pulled through consumption in all years analyzed. Among the digital economy sectors, the contribution rate to consumption was highest for the digital technology application sector, followed by the digital factor-driven and digital product manufacturing sectors, and finally the digital product service sector. From the investment perspective, the contribution rate of the digital economy sector increased from 5.17% in 2007 to 11.11% in 2020, with a more significant increase and surpassing the contribution rate of the digital economy sector to GDP after 2015. Among the digital economy sectors, the digital technology application sector had the highest contribution rate to investment, followed by the digital product manufacturing sector, and finally the digital factor-driven and digital product service sectors. From the perspective of initial input, the contribution rate of the digital economy sector increased from 5.33% in 2007 to 8.19% in 2020, but its proportion in all years analyzed was still lower than the contribution rate of the digital economy sector to GDP. Among the digital economy sectors, the digital technology application sector had the highest contribution rate to initial input, followed by the digital product manufacturing and digital factor-driven sectors, and finally the digital product service sector. However, the contribution rate of the digital product manufacturing sector to initial input has declined since 2015.

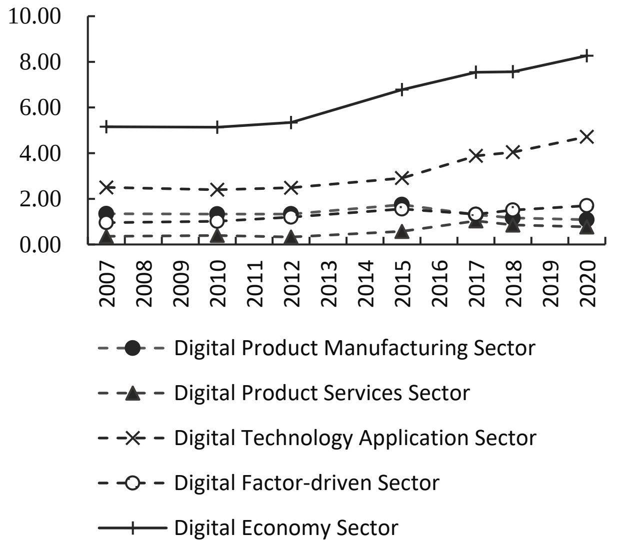

Fig. 8 The contribution rate of digital economy sector to domestic circulation (%)

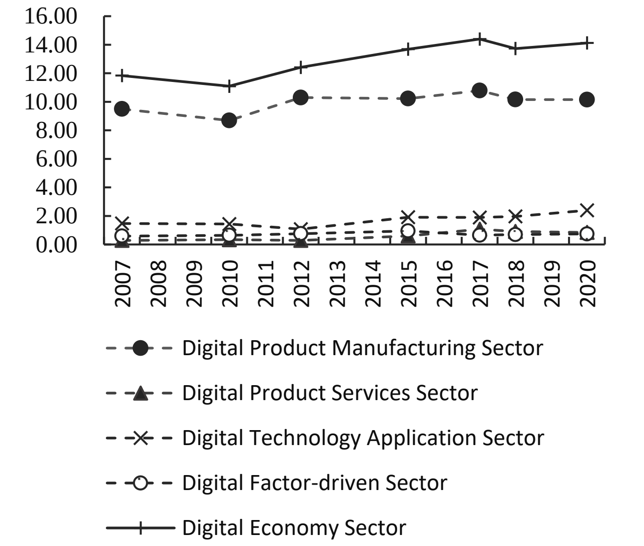

Fig. 9 The contribution rate of digital economy sector to international circulation (%)

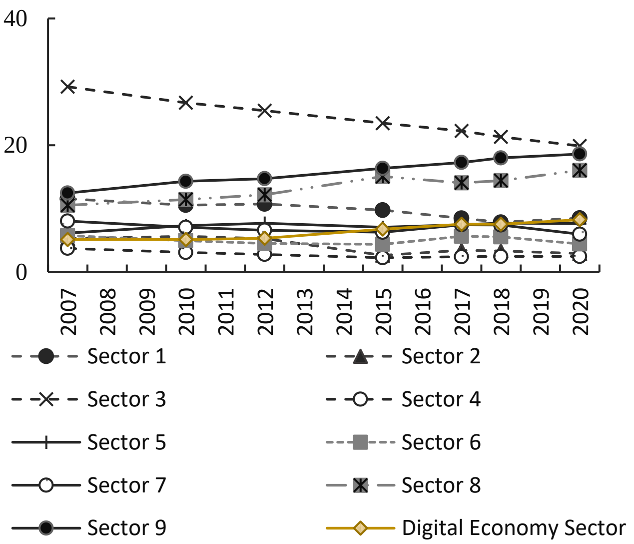

Fig. 10 Contribution rate of each sector to domestic circulation (%)

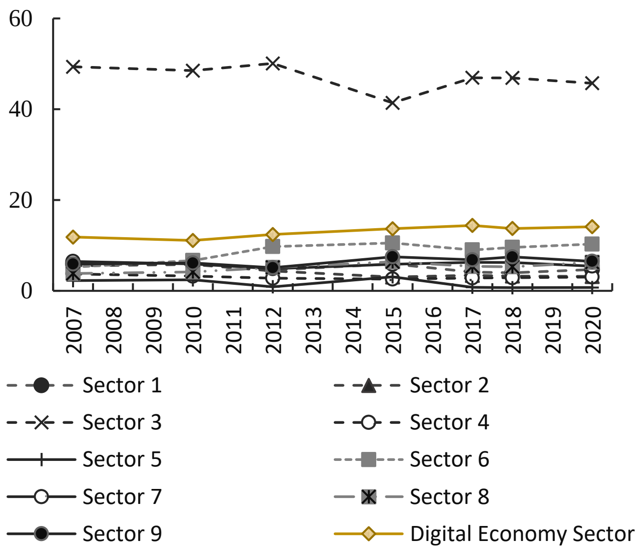

Fig. 11 Contribution rate of each sector to international circulation (%)

Note: Sector 1 refers to agriculture, forestry, and fishery; Sector 2 refers to mining; Sector 3 refers to manufacturing; Sector 4 refers to the production and supply of electricity, heat, gas, and water; Sector 5 refers to construction; Sector 6 refers to wholesale and retail; Sector 7 refers to transportation, warehousing, postal services, accommodation, and catering; Sector 8 refers to finance and real estate; and Sector 10 refers to other service industries. It should be noted that the digital economy segment is excluded from manufacturing, construction, wholesale and retail, finance, and real estate sectors.

Contribution of the digital economy sector to international circulation. This paper measures the contribution of the digital economy sector to international cyclical GDP based on equation (19), as shown in Figure 9. The contribution of the digital economy to international cyclical GDP has remained at a relatively high level, increasing from 11.84% in 2007 to 14.13% in 2020. However, this growth rate has slowed since 2018. Looking internally at the digital economy, this contribution rate mainly comes from the digital product manufacturing industry, indicating that the digital economy sector, represented by products such as communication equipment, computers, and other electronic devices, has a high level of both import and export capabilities. Other digital economy sectors have a relatively stable contribution rate to international cyclical GDP, maintaining between 0.2% and 2.5%. Further decomposition of international cyclical GDP analysis is conducted by analyzing two aspects: export-driven GDP and GDP driven by intermediate imports. Results are shown in Appendix Figures A.4 and A.5. From the export perspective, the contribution rate of the digital economy sector has increased from 10.85% in 2007 to 12.24% in 2020, with its proportion in each year being higher than its contribution rate to GDP. The contribution mainly comes from the digital product manufacturing sector, whose contribution rate to investment-driven GDP has reached 9.21% at one point. From the perspective of intermediate imports, the contribution rate of the digital economy sector has increased from 13.57% in 2007 to 17.76% in 2020, with its proportion in each year being higher than its contribution rate to GDP. The contribution mainly comes from the digital product manufacturing sector, whose contribution rate to GDP driven by intermediate imports has increased from 11.55% in 2007 to 15.66% in 2020. In summary, the total output of the digital economy sector has grown rapidly, with a steady increase in contribution rates, making it an important engine for economic growth. The contribution rates of the different sectors of the digital economy to investment, consumption, and initial input show similar trends. The structural changes in intermediate imports and exports are similar, which provides a reference for the analysis of the contribution rate and structural analysis of the digital economy to the dual cycle. In the domestic cycle, the economic system's demand for technology or products from sectors such as information transmission, software, and information technology services is greater than its demand for sectors such as communication equipment, computers, and other electronic devices. The application of digital technology has gradually replaced the digital product manufacturing sector and become the new driving force of the digital economy. In the international cycle, the digital product manufacturing sector has the highest contribution rate to intermediate imports and exports, making it the main source of contribution to the digital economy sector's contribution rate to international cyclical GDP.

Compared with traditional sectors. In order to further analyze the differences between the digital economy sector and traditional sectors in terms of their contributions to domestic and international GDP, this study calculated the domestic and international GDP contributions of 39 traditional sectors and grouped them into nine categories. These categories were then compared to the digital economy sector to analyze the position of the digital economy sector in the national economic structure and to explore new patterns of development. The contribution rates of each sector to domestic and international GDP are shown in Figure 10 and Figure 11, respectively.

From the breakdown of domestic GDP industries, the contribution rate of the digital economy sector to the domestic GDP has significantly increased and surpassed that of other industries such as wholesale and retail, mining, transportation, and construction, becoming an important driving force for domestic economic circulation. In terms of other industries, while the manufacturing sector has the largest economic scale, its contribution rate to domestic GDP has decreased significantly from 29.22% in 2007 to 19.9% in 2020, indicating that the role of the general manufacturing sector in the national economy continues to decline. The contribution rate of agriculture, forestry, animal husbandry, and fishery to domestic GDP has also decreased from 11.56% in 2007 to 8.51% in 2020, consistent with the changes in China's economic industrial structure. The contribution rate of the construction industry to domestic GDP has slowly increased from 6.15% in 2007 and reached its peak at 7.73% in 2018, maintaining around 7.66% thereafter. This may be due to the relatively stable development of China's urbanization and public facilities. The contribution rates of the financial, real estate, and other service industries to domestic GDP have continued to increase, and their combined contribution rate to domestic GDP has rapidly increased from 23.02% in 2007 to 34.67% in 2020, surpassing that of the manufacturing sector. From the contribution rates and changes of each industry to domestic GDP, the digital economy sector and the tertiary industry are becoming increasingly important in domestic circulation, and China's industrial structure is constantly upgrading. However, the trend of high-level independent innovation-driven industries contributing more to domestic GDP has not yet formed.

In terms of international circulation, the contribution rate of the digital economy sector to international GDP is relatively high, and except for the manufacturing industry, the contribution rates of other industries are lower than that of the digital economy sector. While the manufacturing sector has the largest economic scale, its contribution rate to international GDP has remained stable, whereas the contribution rates of other industries, such as agriculture, forestry, animal husbandry, and fishery, have decreased over time. The contribution rates of the financial, real estate, and other service industries to international GDP have increased rapidly, which is consistent with the trend of globalization and the expansion of international economic cooperation.

5. Factors of international economic circulation

5.1Structural decomposition analysis

Structural Decomposition Analysis (SDA) is a method that can analyze the factors of economic changes by decomposing the change of each explanatory variable in the economy into the sum or product of different independent explanatory variables associated with it, to measure the contribution of each explanatory variable to the change of the explained variable. In this paper, we analyze the factors driving China's dual-cycle development pattern from 2007 to 2020 using non-competitive input-output tables and the SDA method. Considering that GDP is fully decomposed into domestic or international circulation, and we focus on the factors driving the contribution of international circulation in this paper.

From the demand perspective, the contribution of the foreign economic circulation to GDP can be expressed as $\mu'\boldsymbol{A_V}\boldsymbol{BEx} / \mu'\boldsymbol{V}$, where $\boldsymbol{Ex}$ can be further decomposed as the product($e\boldsymbol{L}$)of the share of exports in final demand(e) and final demand($\boldsymbol{L}$), where e is the 55×55 diagonal matrix with the elements on the diagonal representing the share of exports in the final demand of each industry. According to input-output theory, the level of domestic final demand $\boldsymbol{L}$ equals the domestic value added $\boldsymbol{V}$ plus the imported intermediate inputs included in final demand, i.e. $\boldsymbol{L}=$（1+rate of import substitution）, such that $\boldsymbol{L}=\boldsymbol{kV}$, where $\boldsymbol{k}=(\mu'\boldsymbol{L}/\mu'\boldsymbol{V})\boldsymbol{E}$ ， $\boldsymbol{k}$ reflects the import substitution rate of total final demand. From this, the contribution of the foreign economic cycle in each sector can be expressed as $\gamma_f^{demand} = \boldsymbol{\mu' A_V BekV} / \boldsymbol{\mu' V}$. From the supply perspective, the contribution of the foreign economic circulation to GDP can be expressed as $\gamma_f^{supply} = \boldsymbol{\mu' A_V BM} / \boldsymbol{\mu' V}$, where $\boldsymbol{M}$ can be further decomposed as $\boldsymbol{gV}$,which represents the product of the proportion of intermediate inputs to initial inputs of imports(g)and the value added , where g is the 55×55

diagonal matrix with the elements on the diagonal representing the ratio of intermediate inputs to initial inputs of imports in each industry, reflecting the degree of dependence on foreign products in the production process. Thus, the contribution of the foreign economic circulation can be expressed as $\gamma_f^{supply} = \boldsymbol{\mu}'\boldsymbol{A}_V \boldsymbol{B} g \boldsymbol{V} / \boldsymbol{\mu}'\boldsymbol{V}$.

It is suggested in the literature that when using the SDA, the two-polar decomposition method could be adopted as a sound proxy(Dietzenbacher and Los, 1998), i.e., to decompose at the base time and reference time respectively, and then obtain the estimation by averaging the two polar results. Let two-polar be denoted as time 0 and 1, respectively. Firstly, starting from reference time 1, we can write the decomposition equation of foreign circulation rate as:

$$\frac{\gamma_f^1}{\gamma_f^0} = \frac{\mu'\boldsymbol{A}_v^1\boldsymbol{B}^1 e^1 k^1 \boldsymbol{V}^1 + \mu'\boldsymbol{A}_v^1\boldsymbol{B}^1\boldsymbol{m}^1\boldsymbol{V}^1}{\mu'\boldsymbol{A}_v^0\boldsymbol{B}^0 e^0 k^0 \boldsymbol{V}^0 + \mu'\boldsymbol{A}_v^0\boldsymbol{B}^0\boldsymbol{m}^0\boldsymbol{V}^0} \times \frac{2\mu'\boldsymbol{V}^0}{2\mu'\boldsymbol{V}^1} = \frac{\mu'\boldsymbol{A}_v^1\boldsymbol{B}^1(e^1k^1 + \boldsymbol{m}^1)\boldsymbol{V}^1}{\mu'\boldsymbol{A}_v^0\boldsymbol{B}^0(e^0k^0 + \boldsymbol{m}^0)\boldsymbol{V}^0} \times \frac{\mu'\boldsymbol{V}^0}{\mu'\boldsymbol{V}^1} \tag{18}$$

$$\begin{aligned}\frac{\gamma_f^{11}}{\gamma_f^{10}} = {} & \frac{\mu'\boldsymbol{A}_v^1\boldsymbol{B}^1(e^1k^1 + \boldsymbol{m}^1)\boldsymbol{V}^1}{\mu'\boldsymbol{A}_v^0\boldsymbol{B}^1(e^1k^1 + \boldsymbol{m}^1)\boldsymbol{V}^1} \times \frac{\mu'\boldsymbol{A}_v^0\boldsymbol{B}^1(e^1k^1 + \boldsymbol{m}^1)\boldsymbol{V}^1}{\mu'\boldsymbol{A}_v^0\boldsymbol{B}^0(e^1k^1 + \boldsymbol{m}^1)\boldsymbol{V}^1} \times \frac{\mu'\boldsymbol{A}_v^0\boldsymbol{B}^0(e^1k^1 + \boldsymbol{m}^1)\boldsymbol{V}^1}{\mu'\boldsymbol{A}_v^0\boldsymbol{B}^0(e^0k^1 + \boldsymbol{m}^1)\boldsymbol{V}^1} \times \\ & \frac{\mu'\boldsymbol{A}_v^0\boldsymbol{B}^0(e^0k^1 + \boldsymbol{m}^1)\boldsymbol{V}^1}{\mu'\boldsymbol{A}_v^0\boldsymbol{B}^0(e^0k^0 + \boldsymbol{m}^1)\boldsymbol{V}^1} \times \frac{\mu'\boldsymbol{A}_v^0\boldsymbol{B}^0(e^0k^0 + \boldsymbol{m}^1)\boldsymbol{V}^1}{\mu'\boldsymbol{A}_v^0\boldsymbol{B}^0(e^0k^0 + \boldsymbol{m}^0)\boldsymbol{V}^1} \times \frac{\mu'\boldsymbol{A}_v^0\boldsymbol{B}^0(e^0k^0 + \boldsymbol{m}^0)\boldsymbol{V}^1}{\mu'\boldsymbol{A}_v^0\boldsymbol{B}^0(e^0k^0 + \boldsymbol{m}^0)\boldsymbol{V}^0} \times \frac{\mu'\boldsymbol{V}^0}{\mu'\boldsymbol{V}^1}\end{aligned} \tag{19}$$

Secondly, starting from base time 0, the decomposition equation of foreign circulation rate is:

$$\begin{aligned}\frac{\gamma_f^{01}}{\gamma_f^{00}} = {} & \frac{\mu'\boldsymbol{A}_v^1\boldsymbol{B}^0(e^0k^0 + \boldsymbol{m}^0)\boldsymbol{V}^0}{\mu'\boldsymbol{A}_v^0\boldsymbol{B}^0(e^0k^0 + \boldsymbol{m}^0)\boldsymbol{V}^0} \times \frac{\mu'\boldsymbol{A}_v^1\boldsymbol{B}^1(e^0k^0 + \boldsymbol{m}^0)\boldsymbol{V}^0}{\mu'\boldsymbol{A}_v^1\boldsymbol{B}^0(e^0k^0 + \boldsymbol{m}^0)\boldsymbol{V}^0} \times \frac{\mu'\boldsymbol{A}_v^1\boldsymbol{B}^1(e^1k^0 + \boldsymbol{m}^0)\boldsymbol{V}^0}{\mu'\boldsymbol{A}_v^1\boldsymbol{B}^1(e^0k^0 + \boldsymbol{m}^0)\boldsymbol{V}^0} \times \\ & \frac{\mu'\boldsymbol{A}_v^1\boldsymbol{B}^1(e^1k^1 + \boldsymbol{m}^0)\boldsymbol{V}^0}{\mu'\boldsymbol{A}_v^1\boldsymbol{B}^1(e^1k^0 + \boldsymbol{m}^0)\boldsymbol{V}^0} \times \frac{\mu'\boldsymbol{A}_v^1\boldsymbol{B}^1(e^1k^1 + \boldsymbol{m}^1)\boldsymbol{V}^0}{\mu'\boldsymbol{A}_v^1\boldsymbol{B}^1(e^1k^1 + \boldsymbol{m}^0)\boldsymbol{V}^0} \times \frac{\mu'\boldsymbol{A}_v^1\boldsymbol{B}^1(e^1k^1 + \boldsymbol{m}^1)\boldsymbol{V}^1}{\mu'\boldsymbol{A}_v^1\boldsymbol{B}^1(e^1k^1 + \boldsymbol{m}^1)\boldsymbol{V}^0} \times \frac{\mu'\boldsymbol{V}^0}{\mu'\boldsymbol{V}^1}\end{aligned} \tag{20}$$

Thirdly:

$$\frac{\gamma_f^1}{\gamma_f^0} = (1.1) \times (1.2) \times (1.3) \times (1.4) \times (1.5) \times (1.6) \tag{21}$$

Where, (1.1) represents the value added coefficient change effect.

$$(1.1) = \sqrt{\frac{\mu'\boldsymbol{A}_v^1\boldsymbol{B}^1(e^1k^1 + \boldsymbol{m}^1)\boldsymbol{V}^1}{\mu'\boldsymbol{A}_v^0\boldsymbol{B}^1(e^1k^1 + \boldsymbol{m}^1)\boldsymbol{V}^1} \times \frac{\mu'\boldsymbol{A}_v^1\boldsymbol{B}^0(e^0k^0 + \boldsymbol{m}^0)\boldsymbol{V}^0}{\mu'\boldsymbol{A}_v^0\boldsymbol{B}^0(e^0k^0 + \boldsymbol{m}^0)\boldsymbol{V}^0}} \tag{22}$$

(1.2) represents the production structure change effect.

$$(1.2) = \sqrt{\frac{\mu'\boldsymbol{A}_v^0\boldsymbol{B}^1(e^1k^1 + \boldsymbol{m}^1)\boldsymbol{V}^1}{\mu'\boldsymbol{A}_v^0\boldsymbol{B}^0(e^1k^1 + \boldsymbol{m}^1)\boldsymbol{V}^1} \times \frac{\mu'\boldsymbol{A}_v^1\boldsymbol{B}^1(e^0k^0 + \boldsymbol{m}^0)\boldsymbol{V}^0}{\mu'\boldsymbol{A}_v^1\boldsymbol{B}^0(e^0k^0 + \boldsymbol{m}^0)\boldsymbol{V}^0}} \tag{23}$$

(1.3) represents the effect of change in export coefficient.

$$(1.3) = \sqrt{\frac{\mu'\boldsymbol{A}_v^0\boldsymbol{B}^0(e^1k^1 + \boldsymbol{m}^1)\boldsymbol{V}^1}{\mu'\boldsymbol{A}_v^0\boldsymbol{B}^0(e^0k^1 + \boldsymbol{m}^1)\boldsymbol{V}^1} \times \frac{\mu'\boldsymbol{A}_v^1\boldsymbol{B}^1(e^1k^0 + \boldsymbol{m}^0)\boldsymbol{V}^0}{\mu'\boldsymbol{A}_v^1\boldsymbol{B}^1(e^0k^0 + \boldsymbol{m}^0)\boldsymbol{V}^0}} \tag{24}$$

(1.4) represents the effect of change in import substitution rate.

$$(1.4) = \sqrt{\frac{\mu'\boldsymbol{A}_v^0\boldsymbol{B}^0(e^0k^1 + \boldsymbol{m}^1)\boldsymbol{V}^1}{\mu'\boldsymbol{A}_v^0\boldsymbol{B}^0(e^0k^0 + \boldsymbol{m}^1)\boldsymbol{V}^1} \times \frac{\mu'\boldsymbol{A}_v^1\boldsymbol{B}^1(e^1k^1 + \boldsymbol{m}^0)\boldsymbol{V}^0}{\mu'\boldsymbol{A}_v^1\boldsymbol{B}^1(e^1k^0 + \boldsymbol{m}^0)\boldsymbol{V}^0}} \tag{25}$$

(1.5) represents the effect of change in the coefficient of intermediate inputs of imports.

$$(1.5) = \sqrt{\frac{\mu' \underset{v}{\mathbf{A}}^0 \mathbf{B}^0 (e^0 k^0 + \mathbf{m}^1) \mathbf{V}^1}{\mu' \underset{v}{\mathbf{A}}^0 \mathbf{B}^0 (e^0 k^0 + \mathbf{m}^0) \mathbf{V}^1} \times \frac{\mu' \underset{v}{\mathbf{A}}^1 \mathbf{B}^1 (e^1 k^1 + \mathbf{m}^1) \mathbf{V}^0}{\mu' \underset{v}{\mathbf{A}}^1 \mathbf{B}^1 (e^1 k^1 + \mathbf{m}^0) \mathbf{V}^0}} \tag{26}$$

(1.6) represents the initial input change effect.

$$(1.6) = \sqrt{\frac{\mu' \underset{v}{\mathbf{A}}^0 \mathbf{B}^0 (e^0 k^0 + \mathbf{m}^0) \mathbf{V}^1}{\mu' \underset{v}{\mathbf{A}}^0 \mathbf{B}^0 (e^0 k^0 + \mathbf{m}^0) \mathbf{V}^0} \times \frac{\mu' \mathbf{V}^0}{\mu' \mathbf{V}^1} \times \frac{\mu' \underset{v}{\mathbf{A}}^1 \mathbf{B}^1 (e^1 k^1 + \mathbf{m}^1) \mathbf{V}^1}{\mu' \underset{v}{\mathbf{A}}^1 \mathbf{B}^1 (e^1 k^1 + \mathbf{m}^1) \mathbf{V}^0} \times \frac{\mu' \mathbf{V}^0}{\mu' \mathbf{V}^1}} \tag{27}$$

Using the above methodology, it is also possible to decompose the factors driving the contribution of international economic circulation in each industry.

5.2 Factor decomposition.

Decomposition of the international economic circulation. Table 5 gives the decomposition of the international economic circulation through equation (21). In Table 5, the value of each influencing factor level greater than 1 indicates that the factor has a positive impact on the international economic cycle; less than 1 indicates a negative impact on the international economic circulation; the closer the value is to 1, the weaker the impact of a factor on the change of the international economic cycle. During 2007-2010, the contribution rate of international circulation decreased by 37.40% ((1−0.879)×3.097*100%), but increased again by 57.52% ((1−3.097)×0.274*100%) in the period of 2010-2012, and showing a predominantly downward trend after 2012. This is consistent with the main findings above.

Table 5 Factor decomposition of the international economic circulation

	2007-2010	2010-2012	2012-2015	2015-2017	2017-2018	2018-2020
	Level of influence					
Value added coefficient	0.919	1.042	0.932	1.227	1.012	1.008
Production structure	1.105	0.931	1.189	0.806	0.983	1.017
Export coefficient	0.998	1.000	0.999	1.000	1.000	1.001
Import substitution rate	0.999	1.001	0.997	1.000	1.000	1.000
Intermediate inputs of imported goods	0.869	3.194	0.248	0.865	1.068	0.949
Change in initial inputs	0.999	0.999	1.001	0.998	0.999	0.999
Change in international circulation	0.879	3.097	0.274	0.853	1.061	0.972
	Contribution rate					
Value added coefficient	72.84%	1.94%	10.73%	-216.91%	19.21%	-28.12%
Production structure	-95.03%	-3.20%	-29.81%	185.80%	-28.00%	-64.42%
Export coefficient	1.70%	0.01%	0.11%	-0.08%	0.13%	-2.71%
Import substitution rate	0.50%	0.03%	0.47%	0.20%	-0.24%	0.69%
Intermediate inputs of imported goods	118.83%	101.27%	118.58%	129.43%	110.04%	191.36%
Change in initial inputs	1.16%	-0.04%	-0.09%	1.56%	-1.14%	3.20%
Change in international circulation	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

Note: The product of the level of each factor is the level of international circulation change, such as: 0.879 = 0.919 * 1.105 * 0.998 * 0.999 * 0.896 * 0.999; each factor's contribution rate is calculated as 1 minus the value of each factor influence level and then divided by 1 and the sum of each column value difference, for example72.84%= (1-0.919)/ [(1-0.919) +(1-1.105) +(1-0.998) +(1-0.999) +(1-0.869) +(1-0.999)]

The fluctuation of the intermediate input coefficient of imports becomes the primary driver of the change in the level of the international economic circulation, and its contribution is much larger than the change in the coefficient of exports, which is inconsistent with the conclusion above, because if we look only at the share of GDP driven by imports or exports (as shown in Tables 3 and 4), the contribution of exports to the international circulation is higher. The possible reason for this is the phenomenon of importing for exporting in China. China's imports and exports are both growing at a high rate, and there is a correlation between the total volume; however, many enterprises import products that are not often seen in the country, or even not sold in the country at all, but are imported for the sake of export, i.e., imports are a kind of “export-induced” imports. As a result, although the share of GDP driven by exports is higher, it contains a large amount of intermediate inputs of imported goods. This makes the contribution of imports to the international economic cycle higher in the SDA decomposition results. Besides, the effect of changes in production structure and the effect of changes in the value added coefficient have a higher level of impact on the international economic cycle and fluctuate significantly. This indicates that there are certain fluctuations in the use of imported intermediate inputs and export orientation in the production process of each sector, which to some extent indicates that the production process of each sector in China is influenced by the international market and there is a tendency to adjust the production process in time.

Table 6 Factor decomposition of the digital economy sector

	Digital economy sector	Digital Product Manufacturing Sector	Digital Product Services Sector	Digital Technology Application Sector	Digital Factor-driven Sector
Value added coefficient	1.017	1.020	1.027	0.773	1.051
Production structure	1.082	1.073	1.150	1.459	1.043
Export coefficient	0.999	0.999	0.999	0.952	0.996
Import substitution rate	0.999	0.999	0.995	1.007	0.998
Intermediate inputs of imported goods	0.422	0.503	0.169	0.341	0.077
Change in initial inputs	0.737	1.459	0.444	0.514	0.553
Change in international circulation	0.342	0.803	0.760	0.189	0.046

Note: The results are calculated according to equation (23). For example, 1.017 represents the change in the the value added coefficient of the digital economy sector resulting in an increase of 1.7% in the contribution of the digital economy sector to the international economic cycle.

Decomposition of the international economic circulation in the digital economy sector. Based on the aggregate analysis, this paper further decomposes the contribution ratio of the digital economy sector to the international economic cycle, as shown in Table 6. from 2007 to 2020, the contribution of the digital economy sector to the international economic circulation shows an obvious decreasing trend, which is consistent with the conclusion reached above; however, the decomposition results extend this conclusion: from above findings, the ratio of digital economy sector’ GDP formed by both exports and imported intermediate inputs shows a significant decreasing trend during the investigation period. It indicates that the decrease in the contribution of the digital economy sector to the international circulation is the result of the combination of both; however, the SDA decomposition results show that the decrease in the contribution of the digital economy sector is mainly attributed to the change in the coefficient of imported intermediate inputs. This indicates that for a long time, China's digital economy sector has also been importing for export, but this phenomenon has improved in recent years, and the reliance of China's digital economy sector on imported intermediate inputs has declined significantly and has gradually strengthened the main position of the internal circulation. However, this finding is somewhat heterogeneous in terms of the different types of digital economy sectors: digital factor-driven sector and digital product service sector have coefficient change effects of 0.077 and 0.169 for imported intermediate inputs, respectively. It becomes a key factor in the decline of their international circulation contribution. The possible reason is that both are mainly oriented to the domestic market and their imported intermediate inputs are widely replaced by domestic products, which indicates that China's digital economy sector is growing rapidly and forming a high level of self-circulation. The coefficient of imported intermediate inputs in the digital goods manufacturing sector, although also a key driver of the decline in its level of international recycling, is numerically lower than in the other sectors, suggesting that the digital goods manufacturing sector is more dependent on international recycling than the other sectors.

6. Conclusions and policy implications

This article divides the GDP determined by demand and supply into two parts from the perspective of economic circulation: one is the domestic circulation GDP, in which all links in the demand and supply side GDP are realized domestically; the other is the international circulation GDP, which is the domestic GDP realized by the international economy in one of the links in the demand and supply side determined by GDP. Using the relationship between the quantities in the non-competitive input-output table and matrix operations, this article decomposes GDP into domestic circulation GDP and international circulation GDP, and measures the contribution rates of domestic and international circulation through measurable domestic circulation GDP and foreign circulation GDP. At the same time, based on the digital economy input-output table, this article analyzes the contribution rate and structural changes of the digital economy to the domestic and international circulation.

The calculation results show that consumption and initial input are the primary drivers of China's economic growth. The former's contribution rate to GDP on the output demand side fluctuated from 42.05% in 2007 to 49.29% in 2020, and the contribution rate of investment is similar to this. The latter's contribution rate to GDP on the input supply side has steadily increased from 84.78% in 2007 to 92.42% in 2020, far higher than the contribution rate of intermediate input in imported goods. This has led China to form a development pattern with domestic circulation as the main aspect and international circulation as the supplement. The degree of participation of the digital economy sector in domestic and international circulation is similar overall. The contribution rate of domestic circulation to digital economy GDP has fluctuated and increased from 62.02% in 2007 to 82.44% in 2020, and the contribution rate of international circulation to digital economy GDP has fluctuated and decreased from 37.98% in 2007 to 17.56% in 2020. However, the dependence of the digital economy on international circulation is higher than that of traditional industries and is more dependent on exports and imports. In addition, the value added created by the digital economy sector has increased from 1.73 trillion yuan in 2007 to 6.18 trillion yuan in 2020, with an average annual growth rate of 10.31%, higher than the GDP growth rate on the output demand side of 7.71% during the same period, and has become an important driving force for economic growth. From the perspective of the domestic circulation GDP industry breakdown, the contribution rate of the digital economy sector to the domestic economic circulation GDP has increased significantly and has surpassed wholesale and retail, mining, transportation, and construction industries, becoming an important driving force for promoting domestic economic circulation. From the perspective of international circulation, the contribution rate of the digital economy sector to international economic circulation GDP is at a high level, and except for the manufacturing industry; the contribution rate of traditional industries is lower than that of the digital economy sector. From the decomposition results, the international economic circulation is mainly influenced by the effect of change in the coefficient of intermediate inputs of imports.

To better leverage the promotion of the digital economy on the dual circulation, this paper proposes two policy recommendations. From the perspective of the domestic circulation, the focus should be on domestic demand and promoting the deep integration of the digital economy and the real economy. To achieve this, on the one hand, industrial digital platforms should be constructed with the support of big data resources, to promote the deep integration of manufacturing and service industries; on the other hand, digital technology should be used to break through the vertical division of labor in the industrial chain, achieve efficient horizontal integration of elements, and realize the integrated innovation and development of multiple industries, building a mutually beneficial and symbiotic industrial ecosystem for China's dual circulation economy. From the perspective of international circulation, the main breakthrough should be made in intermediate inputs of imported products, gradually achieving import substitution in key technology and product areas. To achieve this, on the one hand, China's institutional advantages of “concentrating resources to accomplish major tasks” should be fully utilized to further strengthen R&D investment in core technologies such as key chips and basic software, and to make up for China's shortcomings in key core technologies and industries. On the other hand, the leading role of key industries and related enterprises in the development of the digital economy should be played, and the main position of enterprises in innovation should be upheld, accurately breaking through the technology bottlenecks and obstacles affecting China's industrial circulation.

Appendix

Table A.1 Sector classification of input-output table

Code	Department Name	Code	Department Name
1	Agriculture, Forestry, and Fishery	21	Instruments and Apparatus
2	Coal Mining Products	22	Other Manufacturing Products and Scrap
3	Petroleum and Natural Gas Products	23	Electricity, Heat Production and Supply
4	Metal Ore Mining Products	24	Gas Production and Supply
5	Non-Metallic and Other Mineral Products	25	Water Production and Supply
6	Food and Tobacco Products	26	Construction
7	Textile Products	27	Wholesale and Retail
8	Textile, Clothing, Footwear, Leather, Down and Related Products	28	Transportation, Storage, and Postal Services
9	Wood Processing and Furniture Products	29	Accommodation and Catering Services
10	Paper, Printing and Cultural, Educational and Sports Equipment	30	Information Transmission, Software and Information Technology Services
12	Chemical Products	32	Real Estate
13	Non-Metallic Mineral Products	33	Leasing and Business Services
14	Metal Smelting and Rolling Products	34	Research and Experimental Development
15	Metal Products	35	Comprehensive Technical Services
16	General Equipment	36	Water Conservancy, Environmental and Public Facility Management
17	Special Equipment	37	Residential Services, Repair, and Other Services
18	Transportation Equipment	38	Education
19	Electrical Machinery and Equipment	39	Health and Social Work
20	Communication Equipment, Computers, and Other Electronic Equipment	40	Culture, Sports, and Entertainment
		41	Public Management, Social Security, and Social Organizations

Table A.2 Separation coefficients for the digital economy

	Sectors	2007	2010	2012	2015	2017	2018	2020
1	Paper, Printing and Cultural, Educational and Sports Equipment	0.022	0.022	0.004	0.008	0.008	0.006	0.007
2	Chemical Products	0.010	0.010	0.017	0.018	0.020	0.008	0.005
3	General Equipment	0.009	0.009	0.027	0.025	0.035	0.026	0.029
4	Special Equipment	0.032	0.032	0.031	0.034	0.018	0.021	0.029
5	Electrical Machinery and Equipment	0.165	0.165	0.207	0.268	0.229	0.221	0.231
6	Instruments and Meters	0.261	0.261	0.394	0.384	0.392	0.361	0.364
7	Wholesale and Retail	0.030	0.030	0.018	0.027	0.074	0.052	0.044
8	Rental and Business Services	0.025	0.025	0.025	0.065	0.098	0.092	0.098
9	Residential Services, Repair and Other Services	0.077	0.077	0.077	0.097	0.037	0.056	0.034
10	Comprehensive Technical Services	0.045	0.045	0.045	0.045	0.030	0.037	0.030
11	Construction	0.020	0.020	0.020	0.020	0.010	0.022	0.028

12	Finance	0.097	0.097	0.108	0.108	0.097	0.100	0.101
13	Research and Experimental Development	0.428	0.428	0.428	0.428	0.368	0.368	0.368
14	Culture, Sports and Entertainment	0.319	0.319	0.319	0.319	0.293	0.289	0.282

Note: Data for 2012, 2017, and 2020 are from the China Industrial Statistics Yearbook and China Statistical Yearbook; there is no relevant data for 2007 and 2008. Considering the stability of the input-output table coefficients, this article uses data from 2008, which comes from the China Economic Census Yearbook. Data for 2018 comes from the China Economic Census Yearbook. For some industry subcategories, there is a lack of revenue data, making it impossible to calculate the separation coefficient for the digital economy. Therefore, it is assumed that these subcategories have the same industry scale, and the separation coefficient for the digital economy in the product department is calculated based on the industry subcategory weights. In addition, because the revenue measurement index began in 2019, main business revenue is used instead of revenue from 2007 to 2018. This is reasonable for two reasons: first, based on recent data, the absolute difference between revenue and main business revenue is relatively stable; second, the growth rates of the two are basically the same. From 2013 to 2018, the difference in growth rates between the main business revenue and revenue of industrial enterprises above a certain scale was basically around 0.1 percentage points. Since 2018, the "revenue" indicator has been published synchronously in the monthly report on industrial economic benefits, and the total difference between the two in 2018 was 2.6%, with a growth rate difference of 0.1 percentage points.

Table A.3 GDP decomposition based on demand side

Type of Digital Economy Sector	Input-Output Table Year	GDP and Contribution Rate (%) Driven by Consumption		GDP and Contribution Rate (%) Driven by Investment		GDP and Contribution Rate (%) Driven by Exports	
Digital Product Manufacturing Sector	2007	779.81	9.65	1396.39	17.28	5905.78	73.07
Digital Product Manufacturing Sector	2010	1000.53	11.05	2288.59	25.28	5765.37	63.67
Digital Product Manufacturing Sector	2012	1737.20	15.60	2959.57	26.58	6438.99	57.82
Digital Product Manufacturing Sector	2015	2697.17	17.39	4331.75	27.93	8477.82	54.67
Digital Product Manufacturing Sector	2017	2740.87	18.66	4252.24	28.95	7694.58	52.39
Digital Product Manufacturing Sector	2018	2526.46	17.66	4442.58	31.06	7333.96	51.28
Digital Product Manufacturing Sector	2020	2700.33	18.65	4411.97	30.47	7369.53	50.89
Digital Product Services Sector	2007	469.67	52.43	184.28	20.57	241.90	27.00
Digital Product Services Sector	2010	653.71	49.03	339.47	25.46	340.18	25.51
Digital Product Services Sector	2012	716.74	50.48	365.15	25.72	337.88	23.80
Digital Product Services Sector	2015	1403.29	46.73	908.10	30.24	691.68	23.03
Digital Product Services Sector	2017	2682.22	43.58	2110.48	34.29	1362.44	22.14
Digital Product Services Sector	2018	2413.65	43.73	1959.57	35.50	1145.98	20.76
Digital Product Services Sector	2020	2391.01	44.43	1847.12	34.32	1143.93	21.25
Digital Technology Application Sector	2007	2942.89	49.26	1960.23	32.81	1071.37	17.93
Digital Technology Application Sector	2010	3300.85	42.95	3277.94	42.66	1105.77	14.39
Digital Technology Application Sector	2012	3928.45	41.23	4696.25	49.29	903.45	9.48
Digital Technology Application Sector	2015	4871.55	33.52	8180.59	56.28	1482.94	10.20
Digital Technology Application Sector	2017	7655.14	35.45	11710.00	54.23	2229.06	10.32
Digital Technology Application Sector	2018	10189.10	41.77	11796.60	48.36	2406.91	9.87

Digital Technology Application Sector	2020	11306.61	36.57	16603.33	53.70	3006.23	9.72
Digital Factor-driven Sector	2007	1137.40	49.21	695.15	30.08	478.72	20.71
Digital Factor-driven Sector	2010	1525.87	46.61	1173.00	35.83	575.00	17.56
Digital Factor-driven Sector	2012	2415.93	47.19	1900.99	37.13	802.23	15.67
Digital Factor-driven Sector	2015	3573.82	46.66	3051.98	39.85	1033.00	13.49
Digital Factor-driven Sector	2017	3607.67	49.00	3089.07	41.96	665.39	9.04
Digital Factor-driven Sector	2018	4204.43	46.33	4169.11	45.94	702.15	7.74
Digital Factor-driven Sector	2020	5216.31	47.32	4951.94	44.92	854.55	7.75
Traditional Sector	2007	105648.06	42.83	77757.66	31.52	63255.64	25.64
Traditional Sector	2010	139791.06	42.71	120715.78	36.88	66792.01	20.41
Traditional Sector	2012	176307.31	44.80	144542.37	36.73	72717.14	18.48
Traditional Sector	2015	229548.40	47.52	173074.19	35.83	80407.87	16.65
Traditional Sector	2017	264571.87	48.67	198704.25	36.55	80363.22	14.78
Traditional Sector	2018	283954.98	48.22	221248.80	37.57	83721.00	14.22
Traditional Sector	2020	319929.34	50.69	222444.78	35.25	88722.87	14.06

Table A.4 GDP decomposition based on supply side

Type of Digital Economy Sector	Input-Output Table Year	GDP and Contribution Rate (%) Driven by Imported Intermediate Inputs		GDP and Contribution Rate (%) Driven by Initial Inputs	
Digital Product Manufacturing Sector	2007	4647.52	57.50	3434.46	42.50
Digital Product Manufacturing Sector	2010	4797.40	52.98	4257.09	47.02
Digital Product Manufacturing Sector	2012	7271.12	65.30	3864.64	34.70
Digital Product Manufacturing Sector	2015	6879.15	44.36	8627.60	55.64
Digital Product Manufacturing Sector	2017	8093.80	55.11	6593.89	44.89
Digital Product Manufacturing Sector	2018	8124.62	56.80	6178.38	43.20
Digital Product Manufacturing Sector	2020	8222.66	56.78	6259.17	43.22
Digital Product Services Sector	2007	74.32	8.30	821.53	91.70
Digital Product Services Sector	2010	68.55	5.14	1264.80	94.86
Digital Product Services Sector	2012	37.61	2.65	1382.16	97.35
Digital Product Services Sector	2015	206.13	6.86	2796.95	93.14
Digital Product Services Sector	2017	200.60	3.26	5954.54	96.74
Digital Product Services Sector	2018	243.98	4.42	5275.22	95.58
Digital Product Services Sector	2020	155.87	2.90	5226.18	97.10
Digital Technology Application Sector	2007	554.29	9.28	5420.21	90.72
Digital Technology Application Sector	2010	637.26	8.29	7047.29	91.71
Digital Technology Application Sector	2012	616.18	6.47	8911.98	93.53
Digital Technology Application Sector	2015	1396.70	9.61	13138.38	90.39
Digital Technology Application Sector	2017	541.93	2.51	21052.27	97.49
Digital Technology Application Sector	2018	586.18	2.40	23806.42	97.60
Digital Technology Application Sector	2020	668.96	2.16	30247.21	97.84
Digital Factor-driven Sector	2007	172.60	7.47	2138.67	92.53
Digital Factor-driven Sector	2010	208.73	6.38	3065.13	93.62
Digital Factor-driven Sector	2012	258.31	5.05	4860.84	94.95

Digital Factor-driven Sector	2015	386.82	5.05	7271.98	94.95
Digital Factor-driven Sector	2017	286.98	3.90	7075.15	96.10
Digital Factor-driven Sector	2018	351.81	3.88	8723.87	96.12
Digital Factor-driven Sector	2020	278.80	2.53	10744.00	97.47
Traditional Sector	2007	34724.73	14.08	211936.62	85.92
Traditional Sector	2010	42416.69	12.96	284882.16	87.04
Traditional Sector	2012	50503.09	12.83	343063.72	87.17
Traditional Sector	2015	49178.09	10.18	433852.38	89.82
Traditional Sector	2017	44919.92	8.26	498719.41	91.74
Traditional Sector	2018	47542.09	8.07	541382.68	91.93
Traditional Sector	2020	43193.08	6.84	587903.90	93.16

Table A.5 Contribution rates of domestic and international circulations to GDP in digital economy sector

Type of Digital Economy Sector	Input-Output Table Year	Contribution Rate (%) of Domestic Circulation	Contribution Rate (%) of International Circulation
Digital Product Manufacturing Sector	2007	34.71	65.29
Digital Product Manufacturing Sector	2010	41.67	58.33
Digital Product Manufacturing Sector	2012	38.44	61.56
Digital Product Manufacturing Sector	2015	50.48	49.52
Digital Product Manufacturing Sector	2017	46.25	53.75
Digital Product Manufacturing Sector	2018	45.96	54.04
Digital Product Manufacturing Sector	2020	46.17	53.83
Digital Product Services Sector	2007	82.35	17.65
Digital Product Services Sector	2010	84.67	15.33
Digital Product Services Sector	2012	86.78	13.22
Digital Product Services Sector	2015	85.05	14.95
Digital Product Services Sector	2017	87.30	12.70
Digital Product Services Sector	2018	87.41	12.59
Digital Product Services Sector	2020	87.92	12.08
Digital Technology Application Sector	2007	86.39	13.61
Digital Technology Application Sector	2010	88.66	11.34
Digital Technology Application Sector	2012	92.03	7.97
Digital Technology Application Sector	2015	90.09	9.91
Digital Technology Application Sector	2017	93.58	6.42
Digital Technology Application Sector	2018	93.86	6.14
Digital Technology Application Sector	2020	94.06	5.94
Digital Factor-driven Sector	2007	85.91	14.09
Digital Factor-driven Sector	2010	88.03	11.97
Digital Factor-driven Sector	2012	89.64	10.36
Digital Factor-driven Sector	2015	90.73	9.27
Digital Factor-driven Sector	2017	93.53	6.47
Digital Factor-driven Sector	2018	94.19	5.81
Digital Factor-driven Sector	2020	94.86	5.14

Traditional Sector	2007	80.14	19.86
Traditional Sector	2010	83.32	16.68
Traditional Sector	2012	84.35	15.65
Traditional Sector	2015	86.59	13.41
Traditional Sector	2017	88.48	11.52
Traditional Sector	2018	88.86	11.14
Traditional Sector	2020	89.55	10.45

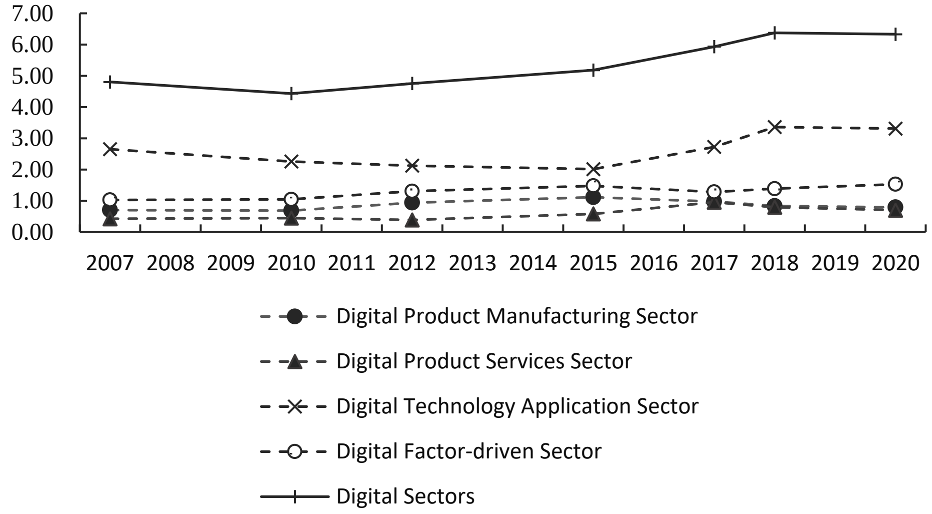

Fig. A.1 Contribution of the digital economy sector to consumption-driven GDP

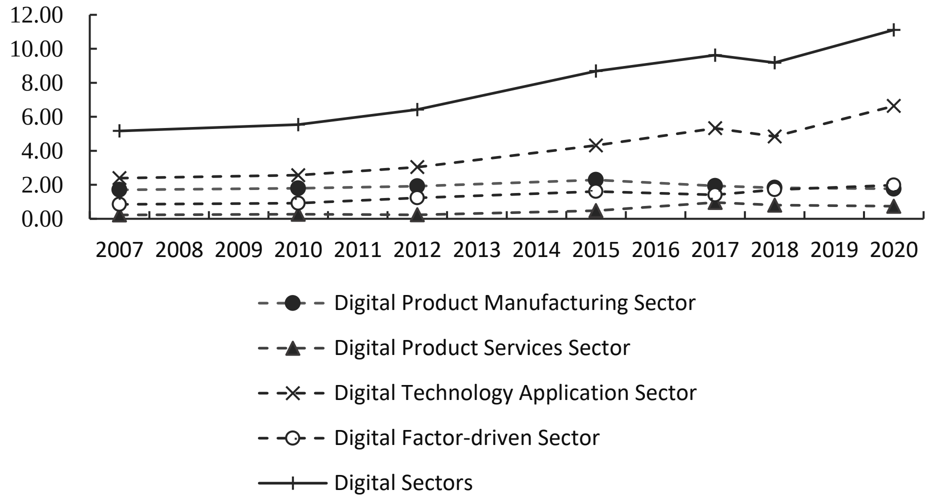

Fig. A.2 Contribution of the digital economy sector to investment-led GDP

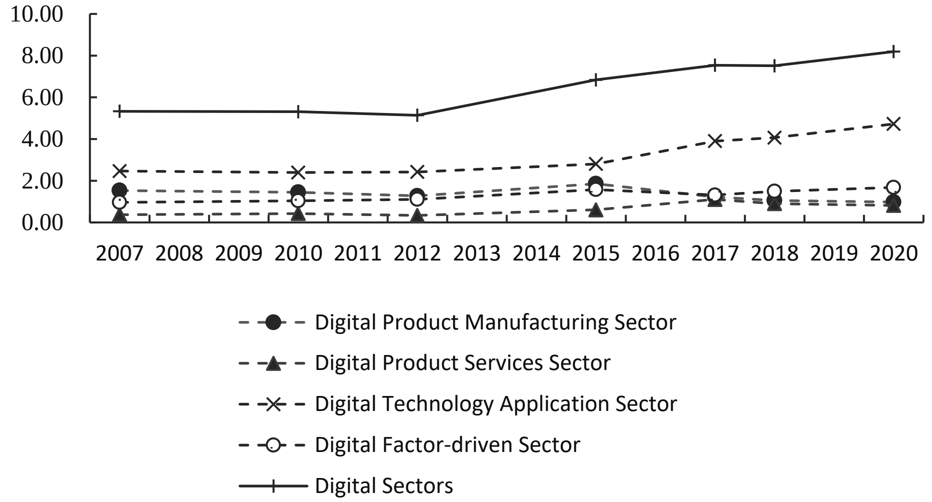

Fig. A.3 Contribution of digital economy sectors to initial input-driven GDP

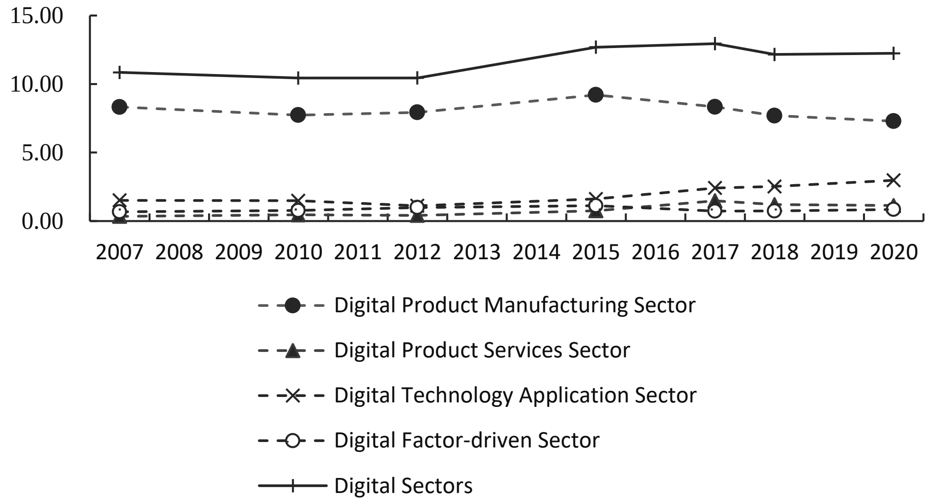

Fig. A.4 Contribution of the digital economy sector to export-led GDP

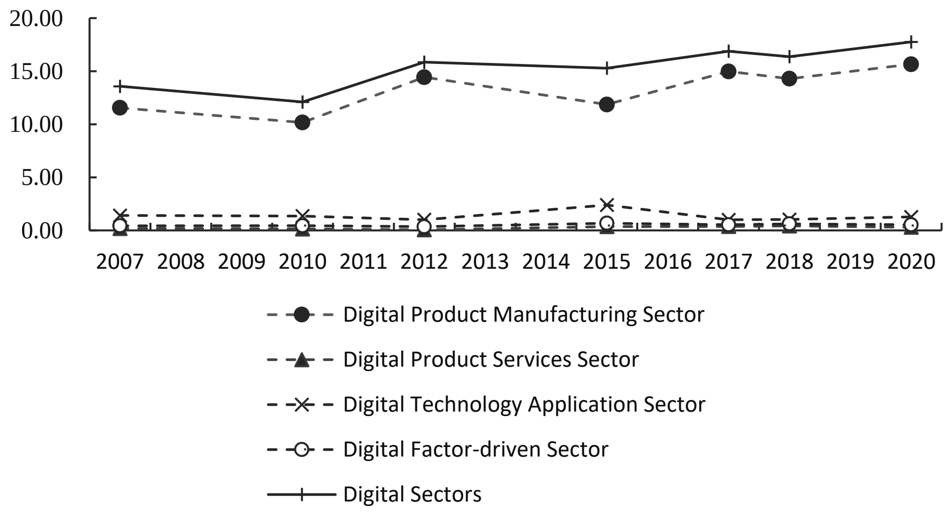

Figure A.5 Contribution of the digital economy sector to GDP driven by intermediate inputs of imports

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