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Tracing the regional dual value chains: Measurement on the production position and evidence from China

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ABSTRACT

When there is insufficient internal and external impetus for developing countries' economy, building a domestic and international dual circulation is conducive to promoting the regional industrial growth. On the basis of regional embedded international input-output tables, this paper extends the measurement framework of production position and proposes the concept of the dual value chain, which measure production position that unifies the national and global value chains from forward and backward industrial linkages. We decompose the national and global value chains into three categories and investigate the production position characteristics of China with a multi-dimensional perspective. Consistent evidence shows that a feasible path of technological progress in optimizing the production in value chains in which technological progress plays a crucial role on the pure national value chain across the high-tech manufacturing sector, the eastern and central regions. Their posterior probabilities are 0.96, 0.21and 0.86, respectively. Moreover, the impact on the dual production is nonnegligible that the posterior probability of technological progress on the eastern and central regions is 0.40 and 0.92. In addition, the impact of the Chinese economic stimulus program and technological progress on the economic crisis has a certain moderating effect. Our proposed evaluation framework sheds new light that national value chain production can boost economic growth , and further promote the coordinated of regional industries for developing countries.

1. Introduction

With the acceleration of globalization and the integration of the domestic market, trade barriers and communication costs have been decreased. In recent times, China has actively participated in global production and developed rapidly in terms of exports. In the meantime, regional trade, international trade, and production patterns have also undergone transformations, whereby production has become more process-oriented and fragmented. Whereas production usually involves different regions and different stages in different countries, the value chain represents the various stages in the production process that bring added value, such as R&D and design, and final goods consumption. Based on territorial characteristics, the specialization of production within the national border has formed the national value chain (NVC) (Meng et al., 2013; Beverelli et al., 2019). On the other hand, value-added cross-border trade (Wang

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et al., 2017) or value-added trade flows cross-border two or more times (Hummels et al., 2001; Beverelli et al., 2019) form the global value chain (GVC). Most products or services are produced by the NVC or GVC, where there are obvious differences in the linkages and relative positions of countries.

In regard to China's participation in international production, it has relied on its labor cost advantage to participate in the form of an Original Equipment Manufacturer (OEM), as well as relying on the fact that the domestic value-added rate of enterprise exports was generally low. This has shown that the transformation of China's role in international production and the promotion and optimization of the value chain position is key to achieving high-quality and sustainable economic development. To cope with the changes in the mode of production and the realistic requirements of China's economic development, extended theoretical methods are urgently needed to capture the new characteristics of the trade pattern. Production length is a basic indicator to measure the GVC, which represents the number of stages in the value chain and reflects the complexity of the production process. Therefore, drawing on measurement of production length (Wang et al., 2017), this paper expanded it to explore regional participation in the production length and production position of different production.

A large number of studies have shown that the current international trade accounting method, which is calculated based on the total value of import and export trade, can no longer accurately reflect the pattern of countries' trade interests in international production. Many scholars and international organizations have advocated and promoted trade value added as the accounting standard for global trade. In this regard, input-output technology is a great tool. The current input-output tables mainly include national input-output tables, regional input-output tables, international input-output tables, and extended input-output tables compiled by scholars (Koopman et al., 2008; Chen et al., 2012; Ma et al., 2015; Meng et al., 2017).

The measurement of production in the value chain is based on different perspectives, and existing research can be classified into the following categories. *Vertical specialization index*. Hummels et al. (2001) used the trade of various countries' intermediate products to reflect the process of specialized production in each country. However, as the vertical specialization index assumes that imported intermediate products are entirely composed of foreign value added, and the same proportion of exports and domestic sales use imported intermediate products. There is a problem of insufficient applicability for countries with a large share of processing trade (hereinafter, this is referred to as the HIY method). Based on this, Koopman et al. (2008) and Yang et al. (2015) relaxed the assumptions of the HIY method to fully consider trade heterogeneity in the calculation, through which they obtained a comprehensive vertical specialization index using a weighted method.

Value-added trade measurement algorithm. Throughout previous studies—from vertical specialization (Hummels et al., 2001) and trade value-added (Johnson & Noguera, 2012) to Koopman et al.'s (2014) total export decomposition—the source of increase in international trade and the basic research context of value-added distribution has been constructed. Since its introduction, follow-up studies (Wang et al., 2014; Los et al., 2016; Miroudot & Ye, 2017; Mudambi & Puck, 2016) have primarily extended the framework (Koopman et al., 2014) to further supplement and improve the total export decomposition method. Under these measurement frameworks, a series of indicators such as the domestic value-added rate in exports and the vertical specialization index can be further measured to reflect the position of a country's value chain production. In addition, some scholars have measured the domestic value-added rate in exports at a more micro-level enterprise level (Upward et al., 2013; Kee & Tang, 2016).

Upstream and downstream measurement algorithm. Dietzenbacher et al. (2005) put forward the concept of Average Propagation Length (APL). When studying the linkages between industries from the perspective of the production chain, the strength of the linkages is related to the distance between industries. Distance can be measured by the APL (Dietzenbacher & Romero, 2007). Fally (2011) proposed measuring the production length of GVC based on two aspects: 'upstreamness' and 'downstreamness'. Antràs et al. (2012), Miller and Temurshoev (2017) measured the position of the sector/country in the global production process. Based on the research of Dietzenbacher et al. (2005), Dietzenbacher and Romero (2007), Antràs and Chor (2013), Escaith and Inomata (2016) proposed a method to measure the average position. On the basis of previous studies, Wang et al. (2017) and Muradov (2017) more accurately measured production in the GVC. Antràs and Gortari (2020) studied the optimal production stage of countries in the presence of international trade barriers. From the existing literature, these research on production in the value chain that is based on the input-output table has gradually matured (Antràs & Chor, 2018).

Compare with previous literature, specifically Wang et al. (2017), this paper proposes the following improvements. (1) The global economic competition pattern has penetrated from the inter-country level to the regional level within a country (Porter & Stern, 2003). With the refinement of the production, for each region within a country, the NVC coexists with the GVC, that is, regions participate in the dual value chain. However, there is no unified analysis framework that accounts for both NVC and GVC at the theoretical level. Previous studies are more concerned with individually measuring NVC or GVC, and there are few studies discussing the internal differences between regions so that they lack a complete description of the value chain from the overall perspective of NVC and GVC production. If we ignore the structural changes in the country's value chain, individually examining the influence mechanism of NVC or GVC may cause endogenous problems because of the cross-influence of NVC and GVC. Therefore, this paper builds a framework for measuring the production position of dual value chain that includes both NVC and GVC.

(2) The fragmentation of the production in the GVC has gradually extended to the domestic, forming a complex production in which the NVC and the GVC are intertwined. The production of a certain product in a region is divided between domestic regions and other countries. This is a mixed production that combines the NVC and GVC, that is, the dual production in the integration of NVC and GVC (abbreviated as NGVC). The difference between NGVC and dual value chain lies in the mainstay of production reflected: NGVC production means that part of the production link of a certain product is completed by NVC, and the other part of the production link is completed by GVC. Thus, all production links of a certain product involve both NVC production and GVC production, reflecting the dual value chain production in the production link of the product. The dual value chain means that when a region (or sector) produces multiple products, the production of some products in the region (or sector) is completed by NVC, and the production of another part of

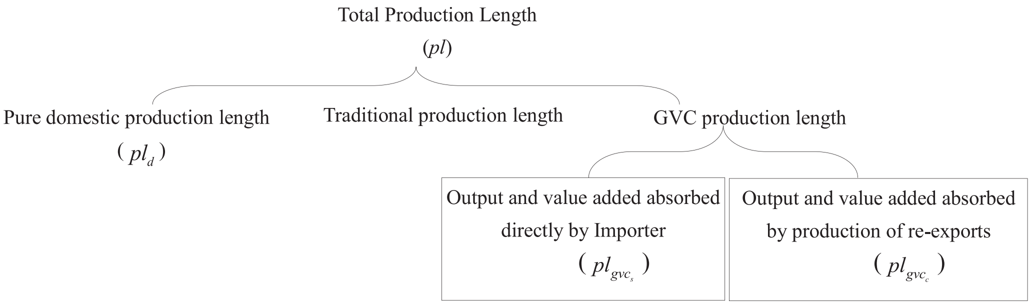

Fig. 1. The index system for production length of Wang et al. (2017).

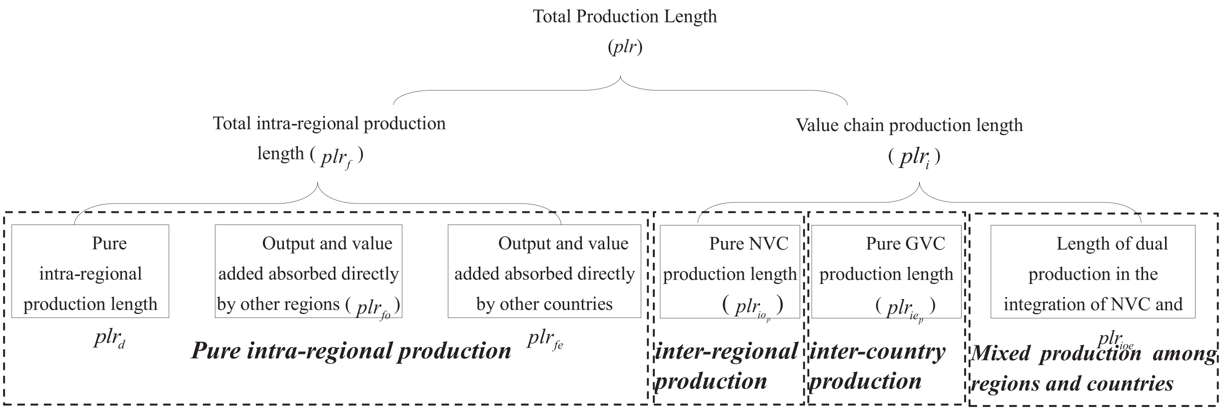

Fig. 2. The Index System for Production Length of this paper.

products is completed by GVC. It creates a situation where the region (or sector) participates in both the NVC production and the GVC production, which reflects the dual value chain production of the region (or sector). Based on the matrix inversion process, the Leontief inverse matrix is further decomposed into pure value chain production (involving only domestic regions or other countries/regions) and a dual production (combining regions and countries/regions). Therefore, this paper can decompose the value chain production into the pure NVC production, the pure GVC production, and the NGVC production, which considers regional heterogeneity and regional international trade. A more detailed value chain analysis framework has been developed to supplement and expand existing research in this paper.

In order to distinguish between the measurement framework of production length proposed by Wang et al. (2017) with this paper, Fig. 1 is the index system for production length proposed by Wang et al. (2017), and Fig. 2 is the index system for production length proposed in this paper. It can be seen from Fig. 1 that the measurement framework of Wang et al. (2017) starts from a country and decomposes the production length in which it participates into pure national production length, traditional production length, and GVC production length. Among them, the production length of the GVC can be further decomposed into the production length of the shallow GVC (pl_{gvc_s}) and the production length of the deep GVC (pl_{gvc_c}).

However, the measurement framework proposed by this paper begins with a certain region within a country, and decomposes the length of production in which it participates into the intra-regional production length and value chain production length. The intra-regional production length includes the pure intra-regional production length (plr_d), the output and value added absorbed directly by other regions (plr_{fo}), and the output and value added absorbed directly by other countries (plr_{fe}). The value chain production length includes the pure NVC production length, the pure GVC production length, and the NGVC production length (that is length of dual production in the integration of NVC and GVC).

Compared with the measurement framework of Wang et al. (2017), this paper has the following advantages. (1) Our research is conducted from the sub-regions within a country rather than the overall level of the country, which is indispensable for countries with large domestic regional development gaps. (2) Further refined on the pure domestic production length (pl_d) of Wang et al. (2017), and we decomposed it into four parts: the pure intra-regional production length (plr_d), Output and value added absorbed directly by other regions (plr_{fo}), pure NVC production length (plr_{io_p}), and the length of dual production in the integration of NVC and GVC (plr_{ioe}), which is conducive to more accurate analysis of the production between various regions in the country and between each region and other countries. (3) The GVC production length of Wang et al. (2017) to be further refined, and we decomposed it into the pure GVC production length (plr_{ie_p}) and the length of dual production in the integration of NVC and GVC (plr_{ioe})in the measurement framework of this paper. The subdivision of the GVC production length may include the process of the NGVC production. It is conductive to understanding the internal regional coordination and production in a country's participation in the GVC production, which is of great significance to alleviating regional development imbalances. It should be noted that these two parts can be further decomposed into the production length of the shallow GVC (pl_{gvc_s}) and the production length of the deep GVC (pl_{gvc_c}) respectively. However, there is no significance for the further production among other countries since already been calculated from a regional perspective.

The remainder of the paper proceeds as follows. Section 2 proposes a framework for measuring the position of regional production from the perspective of dual value chain. Section 3 measures the position of China's regional participation in different segments and analyzes the position characteristics of each region participating in the dual value chain production. Section 4 provides the data and variables description, and sets the empirical estimation. Section 5 analyzes the impact of technological progress on the position in the value chain, and explores the influence path of regional technological progress on the production in the value chain. Then, we provide further evidence to analyze the heterogeneity of regional technological progress on production in the value chain. Section 6 concludes the paper.

2. Theoretical model

2.1. Extension model: the measurement of the embedded production in the dual value chain

Production length is a basic indicator to measure the value chain, which represents the number of stages in the value chain and reflects the complexity of the production process. Drawing on the measurement of GVC production length (Wang et al., 2017), this paper extends the production length measurement to a more detailed regional level, proposes a production length measurement method starting from the regional production, and decomposes the value chain into three categories: pure NVC production, pure GVC production, and NGVC production. From the perspective of the production within and outside the region, it measures the production length from a specific stage to the initial input and final product experience, and calculates the corresponding production position.

2.1.1. Forward decomposition

According to the association relationship reflected by the direct consumption coefficient matrix, A can be decomposed into five parts A^D, A^R, A^{CR}, A^{RC}, and A^C. Among them, A^D and A^R reflect the intra-regional and inter-regional production technology linkages, A^{CR} and A^{RC} reflect the production technology linkages between each region and other countries (or regions), and A^C reflects other countries (or regions) within and between countries (or regions) of production technology linkages. The specific matrix is expressed as

$$A=\begin{bmatrix} A^D+A^R & A^{RC} \\ A^{CR} & A^C \end{bmatrix}$$

$$A^D=\begin{bmatrix} A^R_{11} & \cdots & 0 \\ \cdots & \cdots & \cdots \\ 0 & \cdots & A^R_{ss} \end{bmatrix}; A^R=\begin{bmatrix} 0 & A^R_{12} & \cdots & A^R_{1s} \\ \cdots & \cdots & \cdots & \cdots \\ A^R_{s1} & A^R_{s2} & \cdots & 0 \end{bmatrix}; A^{CR}=\begin{bmatrix} A^{CR}_{21} & \cdots & A^{CR}_{2s} \\ \cdots & \cdots & \cdots \\ A^{CR}_{G1} & \cdots & A^{CR}_{Gs} \end{bmatrix}; \tag{1}$$

$$A^{RC}=\begin{bmatrix} A^{RC}_{12} & \cdots & A^{RC}_{1G} \\ \cdots & \cdots & \cdots \\ A^{RC}_{s2} & \cdots & A^{RC}_{sG} \end{bmatrix}; A^C=\begin{bmatrix} A^C_{22} & \cdots & A^C_{2G} \\ \cdots & \cdots & \cdots \\ A^C_{G2} & \cdots & A^C_{GG} \end{bmatrix}$$

Similarly, the final use column vector Y can also be decomposed into five parts: Y^D, Y^R, Y^{CR}, Y^{RC}, and Y^C, where $Y = \begin{bmatrix} Y^D+Y^R & Y^{RC} \\ Y^{CR} & Y^C \end{bmatrix}$ Y^D and Y^R respectively represent the final use in this region and other regions, $Y^D = \begin{bmatrix} Y^R_{11} & \dots & Y^R_{ss} \end{bmatrix}'$, $Y^R = [\sum^s_{i\neq} Y^R_{1i} \cdots \sum^s_{i\neq s} Y^R_{si} \dots]'$; Y^{CR} and Y^{RC} indicate the final use of regional imports and exports to other countries (or regions), $Y^{CR} = [\sum^s_{i=1} Y^{CR}_{2i} \cdots \sum^s_{i=1} Y^{CR}_{Gi}]'$, $Y^{RC} = [\sum^G_{i=2} Y^{RC}_{1i} \cdots \sum^G_{i=2} Y^{RC}_{si}]'$; Y^C indicates the final use within and between other countries, $Y^C = [\sum^G_{i=2} Y^C_{2i} \cdots \sum^G_{i=2} Y^C_{Gi}]'$. According to the balance relationship of the IRICIOT, the total regional output (X^R) can be expressed as

$$\begin{aligned} X^R &= A^D X^R + Y^D + A^R X^R + Y^R + A^{RC} X^C + Y^{RC} \\ &= \underbrace{(I-A^D)^{-1} Y^D}_{Provided for final use in this region} + \underbrace{(I-A^D)^{-1}(A^R X + Y^R)}_{Provided for use in other regions of the country} + \underbrace{(I-A^D)^{-1}(A^{RC} X + Y^{RC})}_{Provided to other countries} \\ &= \underbrace{(I-A^D)^{-1} Y^D}_{Provided for final use in this region} + \underbrace{(I-A^D)^{-1} Y^R}_{Provide final goods to other regions of the country} + \underbrace{(I-A^D)^{-1} Y^{RC}}_{Provide final goods to other countries} \\ &+ \underbrace{(I-A^D)^{-1} A^R\left[(B^D+B^R)(Y^D+Y^R+Y^{RC}) + B^{RC}(Y^{CR}+Y^C)\right]}_{Provide intermediate products to other regions of the country} \\ &+ \underbrace{(I-A^D)^{-1} A^{RC}\left[B^{CR}(Y^D+Y^R+Y^{RC}) + B^C(Y^{CR}+Y^C)\right]}_{Provided Intermediate products to other countries} \end{aligned} \tag{2}$$

As mentioned in the induction of literature review, the index of upsteamness proposed by Antràs et al. (2012) is based on forward industrial linkage, shows that positions on the global production chain can be expressed as the weighted average distance between the various intermediate products that make up the final goods (that is, how many stages of production are produced to become the final goods). The longer the production chain, the greater the number of upstream stages of production in which a particular final good is located in the economy. Similarly, the greater the upstreamness index, the farther away the production is from the weighted average distance of the final demand (and the closer it is to the upstream). Combining the decomposition formula of regional total output (X^R) (Eq. 2), starting from the regional value added, the value added of each region can be determined according to the following Eq. (3).

$$
\begin{aligned}
Va^R &= \hat{V}^R X^R \\
&= \underbrace{\hat{V}^R L^R Y^D + \hat{V}^R L^R Y^R + \hat{V}^R L^R Y^{RC}}_{①\text{Total Intra-regional production}} + \underbrace{\hat{V}^R L^R A^R B_1 Y + \hat{V}^R L^R A^{RC} B_2 Y}_{②\text{Value chain production}} \\
&= \underbrace{\hat{V}^R L^R Y^D}_{①_1\text{Intra-regional production}} + \underbrace{\hat{V}^R L^R Y^R}_{①_2\text{Inter-regional final goods trade}} + \underbrace{\hat{V}^R L^R Y^{RC}}_{①_3\text{Regional-international final goods trade}} \\
&+ \underbrace{\hat{V}^R L^R A^R B^{DR} \delta^R Y}_{②_1\text{Pure NVC production}} + \underbrace{\hat{V}^R L^R A^{RC} B^{CC} \delta^C Y}_{②_2\text{Pure GVC production}} + \underbrace{\hat{V}^R L^R A^R \left(B_1 - B^{DR}\delta^R\right) Y + \hat{V}^R L^R A^{RC} \left(B_2 - B^{CC}\delta^C\right) Y}_{②_3\text{NGVC production}}
\end{aligned}
\tag{3}
$$

Among them, $\hat{V}^R$ is the regional value added coefficient matrix after the diagonalization of V^R, $L^R = (I - A^D)^{-1}$ represents the technical and economic ties within the region, $A = \begin{bmatrix} A^D + A^R & A^{RC} \\ A^{CR} & A^C \end{bmatrix}$ is the direct consumption coefficient matrix, $B = (I - A)^{-1} = \begin{bmatrix} B^D + B^R & B^{RC} \\ B^{CR} & B^C \end{bmatrix}$ is the global Leontief inverse matrix, representing the global technological and economic linkages. $B_1 = [B^D + B^R \quad B^{RC}]$ indicates starting from the region, and technical and economic ties with other regions and countries, $B_2 = [B^{CR} \quad B^C]$ indicates the technical and economic ties between the country and the region and other countries. Since B_1 is the regional block matrix of the global Leontief inverse matrix, there may be other countries participating in different segments of production. Therefore, the pure NVC production is further separated from it, B^{DR}, $B^{DR} = [I - (A^D + A^R)]^{-1}$ represents purely technical and economic relations within and between regions. Since B_2 is the country block matrix of the global Leontief inverse matrix, there may be target country participating in different segments of production. Therefore, the pure GVC production is further separated from it (without regions of target country), B^{CC}, $B^{CC} = (I - A^C)^{-1} = [I - (A^{CD} + A^{CF})]^{-1}$ represents purely technical and economic relations within and between countries (without target country). A^{CD} is the diagonal block matrix of A^C, reflecting the internal production technology linkages of the countries (or regions); A^{CF} is the non-diagonal block matrix of A^C, reflecting the production technology linkages between countries (or regions). $\delta^R = \left[I_{s*s} \quad 0_{s*(G-1)} \right]$, $\delta^C = \left[0_{(G-1)*s} \quad I_{(G-1)*(G-1)} \right]$, $Y = [Y_1 \quad Y_2]'$ is the final use vector, $Y_1 = Y^D + Y^R + Y^{RC}$ represents the sum of the final use within a region, between regions and the exports of the region, $Y_2 = Y^{CR} + Y^C$ indicates the final use of the country's exports to the region and other countries.

According to the different segments of production, regional value-added decomposition can be divided into two parts: total intra-regional production and value chain production. Furthermore, the regional value-added brought by the total intra-regional production can be divided into three parts: the regional value-added brought by the intra-regional production ($\hat{V}^R L^R Y^D$), the regional value added brought by the trade of final goods between regions ($\hat{V}^R L^R Y^R$), and the regional value added brought by international final goods trade ($\hat{V}^R L^R Y^{RC}$). The first part reflects the contribution of the final demand in the region to the value added of the region (that is, home bias at the regional level). The second and third parts reflect the contribution of demand for the final goods outside the region to the regional value added (that is, traditional trade at the regional level). The regional value added brought about by the production in the value chain can be further divided into three parts. (1) Pure NVC production. It reflects the fact that intermediate products only flow repeatedly in various regions of a target country. This is the embodiment of intra-product production under the vertical production system at the regional level within a country. (2) Pure GVC production. It reflects the situation that intermediate products only flow repeatedly in other countries after they are exported, which is a reflection of the intra-product production at the national level under the vertical production system. (3) NGVC production. It reflects the repeated flow of intermediate products between regions of a target country and other countries, and it is a complex production process in the integration of NVC and GVC. Among them, the dual production that is further carried out after providing intermediate products to other regions of target country is $\hat{V}^R L^R A^R (B_1 - B^{DR}\delta^R) Y$, and the dual production that is further carried out after providing intermediate products to other countries is $\hat{V}^R L^R A^{RC} (B_2 - B^{CC}\delta^C) Y$.

Total average production length. The total average production length refers to the average number of times the value added created by production factors is counted as the total output in a continuous production process. First, the regional value added can be expressed as

$$
Va^R = \hat{V}^R X^R = \hat{V}^R B_1 Y = \hat{V}^R \left(\delta^R B\right) Y = \hat{V}^R \left[\delta^R \left(I + A + A^2 + \ldots\right)\right] Y \tag{4}
$$

In each continuous production process, the longer the production chain, the smaller the value-added share reaching the final user, such that the decreasing value-added share is used as the weight for weighing (Muradov, 2017). Each item in $I + A + A^2 + \ldots$ corresponds to the number of productions between the producer and the final user. I, A, and A^2 respectively indicate that the export of intermediate products involves 1 final production stage, 1 final production stage and 1 intermediate production stage, 1 final production stage and 2 intermediate production stages, whereby the corresponding production stages are 1, 2, 3. Then, based on the forward industrial linkage, the total average production length of the region weighted by the decreasing value-added share can be expressed as

$$plvr = \frac{\widehat{V}^R[\delta^R(1*I+2*A+3*A^2+\dots)]Y}{\widehat{V}^R[\delta^R(I+A+A^2+\dots)]Y} = \frac{\widehat{V}^R B_1 BY}{\widehat{V}^R B_1 Y} \tag{5}$$

It can be determined from Eq. (5) that the total average production length based on the forward industrial linkage is equal to the ratio of the total output caused by the value added ($\widehat{V}^R B_1 BY$) to the corresponding value added ($\widehat{V}^R B_1 Y$).

Length of the total intra-regional production. Based on Eq. (3), the value added brought by the final goods trade is $\widehat{V}^R L^R(Y^D + Y^R + Y^{RC})$ can be known. Similar to the total average production length, it is weighted with the decreasing value-added share as the weight. Since the production segments do not involve cross-border and cross-regional production, which is identified as a pure intra-regional production. The average production length of total intra-regional production can be expressed as

$$plvr_f = \frac{\widehat{V}^R(1*I+2*A^D+3*A^{D2}+\dots)(Y^D+Y^R+Y^{RC})}{\widehat{V}^R(I+A^D+A^{D2}+\dots)(Y^D+Y^R+Y^{RC})} = \frac{\widehat{V}^R L^R L^R(Y^D+Y^R+Y^{RC})}{\widehat{V}^R L^R(Y^D+Y^R+Y^{RC})} = \frac{\widehat{V}^R L^R L^R \delta^R Y}{\widehat{V}^R L^R \delta^R Y} \tag{6}$$

Furthermore, depending on the different trade destinations, the average production length corresponding to the intra-regional production, inter-regional final goods trade, and regional-international final goods trade can be expressed separately, $plvr_d$, $plvr_{fo}$, $plvr_{fe}$.

$$plvr_d = \frac{\widehat{V}^R L^R L^R Y^D}{\widehat{V}^R L^R Y^D}; plvr_{fo} = \frac{\widehat{V}^R L^R L^R Y^R}{\widehat{V}^R L^R Y^R}; plvr_{fe} = \frac{\widehat{V}^R L^R L^R Y^{RC}}{\widehat{V}^R L^R Y^{RC}} \tag{7}$$

Length of the value chain production. As analyzed above, it can be seen that the production in the value chain of regional participation mainly includes NVC production and GVC production. Among them, the regional value added by the NVC production is $\widehat{V}^R L^R A^R B_1 Y$, and the regional value added by the GVC production is $\widehat{V}^R L^R A^{RC} B_2 Y$. From the perspective of production outside the region, the average production length of the value chain can be expressed as

$$\begin{aligned} plvr_i &= \frac{\widehat{V}^R L^R A^R[\delta^R(1*I+2*A+3*A^2+\dots)]Y + \widehat{V}^R L^R A^{RC}[\delta^C(1*I+2*A+3*A^2+\dots)]Y}{\widehat{V}^R L^R[\delta^R(I+A+A^2+\dots)]Y + \widehat{V}^R L^R A^{RC}[\delta^C(I+A+A^2+\dots)]Y} \\ &= \frac{\widehat{V}^R L^R A^R(\delta^R BB)Y + \widehat{V}^R L^R A^{RC}(\delta^C BB)Y}{\widehat{V}^R L^R(\delta^R B)Y + \widehat{V}^R L^R A^{RC}(\delta^C B)Y} = \frac{\widehat{V}^R L^R A^R B_1 BY + \widehat{V}^R L^R A^{RC} B_2 BY}{\widehat{V}^R L^R B_1 Y + \widehat{V}^R L^R A^{RC} B_2 Y} \end{aligned} \tag{8}$$

It can be seen that the value added corresponding to a pure NVC production can be expressed as $\widehat{V}^R L^R A^R B^{DR} \delta^R Y$ in Eq. (3), and the inter-region production is the focus of this paper. Therefore, from the perspective of inter-region production, the average production length of pure NVC production can be expressed as

$$plvr_{io_p} = \frac{\widehat{V}^R L^R A^R\left[1*I+2*(A^D+A^R)+3*(A^D+A^R)^2+\dots\right]\delta^R Y}{\widehat{V}^R L^R A^R\left[I+(A^D+A^R)+(A^D+A^R)^2+\dots\right]\delta^R Y} = \frac{\widehat{V}^R L^R A^R B^{DR} B^{DR} \delta^R Y}{\widehat{V}^R L^R A^R B^{DR} \delta^R Y} \tag{9}$$

The regional value added brought by pure GVC production is $\widehat{V}^R L^R A^{RC} B^{CC} \delta^C Y$. Similarly, the average production length of pure GVC production can be expressed as

$$plvr_{ie_p} = \frac{\widehat{V}^R L^R A^{RC}\left[1*I+2*(A^{CD}+A^{CF})+3*(A^{CD}+A^{CF})^2+\dots\right]\delta^C Y}{\widehat{V}^R L^R A^{RC}\left[I+(A^{CD}+A^{CF})+(A^{CD}+A^{CF})^2+\dots\right]\delta^C Y} = \frac{\widehat{V}^R L^R A^{RC} B^{CC} B^{CC} \delta^C Y}{\widehat{V}^R L^R A^{RC} B^{CC} \delta^C Y} \tag{10}$$

In the national and global segments of production, both regions and other countries participate at the same time. The value added brought by this production is the regional value added brought by the NGVC production. Among them, the regional value added brought by the dual production in the NVC production is $\widehat{V}^R L^R A^R(B_1 - B^{DR}\delta^R)Y$, and the regional value added brought by the dual production in the GVC production is $\widehat{V}^R L^R A^{RC}(B_2 - B^{CC}\delta^C)Y$. From the perspective of production outside the region, the average production length of the NGVC production can be expressed as

$$\begin{aligned} plvr_{ioe} &= \frac{\widehat{V}^R L^R A^R B(u^R BB - B^{DR} B^{DR} \delta^R)Y + \widehat{V}^R L^R A^{RC}(u^C BB - B^{CC} B^{CC} \delta^C)Y}{\widehat{V}^R L^R A^R(B_1 - B^{DR}\delta^R)Y + \widehat{V}^R L^R A^{RC}(B_2 - B^{CC}\delta^C)Y} \\ &= \frac{\widehat{V}^R L^R A^R(B_1 B - B^{DR} B^{DR} \delta^R)Y + \widehat{V}^R L^R A^{RC}(B_2 B - B^{CC} B^{CC} \delta^C)Y}{\widehat{V}^R L^R A^R(B_1 - B^{DR}\delta^R)Y + \widehat{V}^R L^R A^{RC}(B_2 - B^{CC}\delta^C)Y} \end{aligned} \tag{11}$$

From the perspective of production within and outside the region, the sum of the total output caused by the regional value added brought about by different segments of production is consistent with the overall level of measurement results. The accuracy of the decomposition framework based on forward industrial linkage is verified (more detail see Appendix A).

2.1.2. Backward decomposition

From the perspective of backward industrial linkage, the average production length can be expressed as the weighted average distance from the final goods to the initial input. The larger the average production length, the farther the production is from the weighted average distance of the initial input, and the closer it is to the downstream position of the production chain. Based on the backward industrial linkage, starting from the regional final goods, the regional final use vector can be divided into different production paths as follows.

$$\begin{aligned}(Y_1)' &= \delta\hat{Y}_1 = VB\mu\hat{Y}_1 = VB\hat{Y}\mu = V^R B_1\hat{Y}\mu + V^C B_2\hat{Y}\mu \\ &= V^R L^R \delta^R \hat{Y}\mu + V^R L^R A^R B_1 \hat{Y}\mu + V^R L^R A^{RC} B_2 \hat{Y}\mu \\ &+ V^C L^C \delta^C \hat{Y}\mu + V^C L^C A^{CF} B_2 \hat{Y}\mu + V^C L^C A^{CR} B_1 \hat{Y}\mu \\ &= \underbrace{V^R L^R \hat{Y}^D}_{①_1 Intra-regional\ production} + \underbrace{V^R L^R \hat{Y}^R}_{①_2 Inter-regional\ final\ goods\ trade} + \underbrace{V^R L^R \hat{Y}^{RC}}_{①_3 Regional-international\ final\ goods\ trade} \\ &+ \underbrace{V^R L^R A^R B^{DR} \delta^R \hat{Y}\mu}_{②_1 Pure\ NVC\ production} + \underbrace{V^C L^C A^{CR} L^R \delta^R \hat{Y}\mu}_{②_2 Pure\ GVC\ production} + \underbrace{\left\{\begin{array}{l} V^R L^R A^R (B_1 - B^{DR}\delta^R)\hat{Y}\mu + V^R L^R A^{RC} B_2 \hat{Y}\mu \\ + V^C L^C A^{CF} B_2 \hat{Y}\mu + V^C L^C A^{CR} (B_1 - L^R \delta^R)\hat{Y}\mu \end{array}\right\}}_{②_3 NGVC\ production}\end{aligned} \tag{12}$$

Among them, $\mu = \begin{bmatrix} I_{s*s} & 0_{s*C} \\ 0_{C*s} & 0_{C*C} \end{bmatrix}$, $L^C = (I - A^{CD})^{-1}$ represents a country's technical and economic ties, $\delta = [1, \ldots, 1]$. From the perspective of the columns in the IRICIOT, the sum of intermediate input and initial input is the total input, which can be expressed either as $X' = (AX)' + V\hat{X}$ or $\delta\hat{X} = \delta A\hat{X} + V\hat{X}$, so $\delta = V(I-A)^{-1} = VB$. Regional final use (Y_1) include three situations: final use in the region, final use in other regions, and final use in other countries. Therefore, imported intermediate products are used in these three production paths, and the final use part of imported intermediate products from other countries is 0. In the above Eq. (12), $V^R L^R \hat{Y}^D + V^R L^R \hat{Y}^R + V^R L^R \hat{Y}^{RC}$ indicates that the initial input of the region is directly used for final goods production, which is used to meet the final demand in the region, the final goods demand of other regions, and the final goods demand of other countries/regions. $V^R L^R A^R B^{DR} \delta^R \hat{Y}\mu$ indicates that the initial inputs of the region are used for production. The entire production process does not involve the participation of other countries (or regions), so it is recorded as pure NVC production. $V^C L^C A^{CR} L^R \delta^R \hat{Y}\mu$ indicates that the initial input and intermediate input of other countries (or regions) are used for production. After the regional import does not involve other regional production in the target country, it is recorded as a pure GVC production. $V^R L^R A^R (B_1 - B^{DR}\delta^R)\hat{Y}\mu + V^R L^R A^{RC} B_2 \hat{Y}\mu + V^C L^C A^{CF} B_2 \hat{Y}\mu + V^C L^C A^{CR} (B_1 - L^R\delta^R)\hat{Y}\mu$ indicates using the initial inputs of the region or other countries (or regions) for production. During the production process, both the target country's region and other countries participate in production. Therefore, this part is the dual production in the integration of NVC and GVC, that is NGVC production.

Total average production length. The backward industrial linkage between regional sectors can be expressed as the sum of the initial inputs of all upstream sectors that contribute to the final goods of a specific regional sectoral unit. Consistent with the forward decomposition, a decreasing weight is still used to weigh the number of production stages. Therefore, the total average production length based on backward industrial linkage can be expressed as

$$plyr = \frac{V(1*I + 2*A + 3*A^2 + \ldots)\hat{Y}\mu}{V(I + A + A^2 + \ldots)\hat{Y}\mu} = \frac{VBB\hat{Y}\mu}{VB\hat{Y}\mu} \tag{13}$$

Among them, $VB\hat{Y}\mu$ is the final use vector of the region, and $VBB\hat{Y}\mu$ represents the total input of the final goods in the region after weighing all production stages. According to the production experienced at different stages, the number of production stages is weighed with a decreasing final use share. If the initial input in this region is directly applied to the final goods production in this region, the length of the production chain is 1. If other regions provide initial input to this region, after the production in this region is an intermediate product, it will be further used in the production of final goods in this region. This part uses the initial input from other regions as the total input contained in the production of final goods in this region. At this time, the length of the production chain is 2, and so on, the corresponding weights are 1, 2, 3. respectively.

Length of the total intra-regional production. It can be seen from Eq. (12) that the final use corresponding to the intra-regional production and the final goods trade outside the region is $V^R L^R \delta^R \hat{Y}\mu$. At this time, all production processes are completed within the region, without involving other regions. In order for countries (or regions) to reflect the production process more clearly in the region, L^R can be expressed as $I + A^D + A^{D2} + \ldots$, whereby the number of production stages corresponding to each item is 1, 2, 3. After weighing, the average production length of total intra-regional production is

$$plyr_f = \frac{V(1*I + 2*A^D + 3*A^{D2} + \ldots)\hat{Y}\mu}{V(I + A^D + A^{D2} + \ldots)\hat{Y}\mu} = \frac{V^R L^R L^R \delta^R \hat{Y}\mu}{V^R L^R \delta^R \hat{Y}\mu} \tag{14}$$

The corresponding average production length of intra-regional production, inter-regional final goods trade, and regional-international finals product trade can be expressed as

$$plyr_d = \frac{V^R L^R L^R \widehat{Y}^D}{V^R L^R \widehat{Y}^D}; plyr_{fo} = \frac{V^R L^R L^R \widehat{Y}^R}{V^R L^R \widehat{Y}^R}; plyr_{fe} = \frac{V^R L^R L^R \widehat{Y}^{RC}}{V^R L^R \widehat{Y}^{RC}} \tag{15}$$

Length of the value chain production. For production in the value chain, there is production within the region and production outside the region. Since regional production only reflects circular production within the region itself, it cannot reflect the inter-regional, regional-international production linkage. Therefore, when calculating the average production length of production in the value chain, the analysis is performed from the perspective of production outside the region.

It can be seen from Eq. (12) that for the production of regional final goods, the initial input of the region or other countries (or regions) is adopted for the production of intermediate products, and the final goods produced is $V^R L^R A^R B_1 \widehat{Y}\mu + V^R L^R A^{RC} B_2 \widehat{Y}\mu + V^C B_2 \widehat{Y}\mu$, recorded as yr_i. From the perspective of production outside the region, and in the process of producing regional final goods, B_1 and B_2 reflect the process of production outside the region. According to the relationship between B_1, B_2, and B, B_1 can be expressed as $\delta^R(I + A + A^2 + \ldots)$, B_2 can be expressed as $\delta^C(I + A + A^2 + \ldots)$. Then, the total input caused by the production in the value chain (wyr_i) can be expressed as

$$\begin{aligned} wyr_i &= V^R L^R A^R \left[\delta^R \left(1 * I + 2 * A + 3 * A^2 + \ldots\right)\right] \widehat{Y}\mu \\ &+ V^R L^R A^{RC} \left[\delta^C \left(1 * I + 2 * A + 3 * A^2 + \ldots\right)\right] \widehat{Y}\mu \\ &+ V^C \left[\delta^C \left(1 * I + 2 * A + 3 * A^2 + \ldots\right)\right] \widehat{Y}\mu \\ &= V^R L^R A^R \left(\delta^R BB\right) \widehat{Y}\mu + V^R L^R A^{RC} \left(\delta^C BB\right) \widehat{Y}\mu + V^C \left(\delta^C BB\right) \widehat{Y}\mu \\ &= V^R L^R A^R B_1 B \widehat{Y}\mu + V^R L^R A^{RC} B_2 B \widehat{Y}\mu + V^C B_2 B \widehat{Y}\mu \end{aligned} \tag{16}$$

Therefore, from the perspective of production outside the region, the average production length of the value chain production can be expressed as

$$plyr_i = \frac{wyr_i}{yr_i} \tag{17}$$

It can be seen that the final use corresponding to a pure NVC production based on backward industrial linkage is $V^R L^R A^R B^{DR} \delta^R \widehat{Y}\mu$. From the perspective of production outside the region, $B^{DR} = [I - (A^D + A^R)]^{-1}$ reflects the out-of-region production process. To reflect the various production stages more clearly it contains B^{DR} , which can be expressed as $I + (A^D + A^R) + (A^D + A^R)^2 + \ldots$. The number of production stages corresponding to each item is 1, 2, 3. Then, the average production length of a pure NVC production can be expressed as

$$plyr_{io_p} = \frac{V^R L^R A^R \left[1 * I + 2 * \left(A^D + A^R\right) + 3 * \left(A^D + A^R\right)^2 + \ldots\right] \delta^R \widehat{Y}\mu}{V^R L^R A^R \left[I + \left(A^D + A^R\right) + \left(A^D + A^R\right)^2 + \ldots\right] \delta^R \widehat{Y}\mu} = \frac{V^R L^R A^R B^{DR} B^{DR} \delta^R \widehat{Y}\mu}{V^R L^R A^R B^{DR} \delta^R \widehat{Y}\mu} \tag{18}$$

The final use corresponding to pure GVC production based on the backward industrial linkage is $V^C L^C A^{CR} L^R \delta^R \widehat{Y}\mu$. At this time, other regions or countries are no longer involved in the production after the regional import. Therefore, the production process that occurs after import only occurs in the import region, and the corresponding production linkage matrix is $L^R = I + A^D + A^{D2} + \ldots$. Therefore, the average production length of pure GVC production can be expressed as

$$plyr_{ie_p} = \frac{V^C L^C A^{CR} \left(1 * I + 2 * A^D + 3 * A^{D2} + \ldots\right) \delta^R \widehat{Y}\mu}{V^C L^C A^{CR} \left(I + A^D + A^{D2} + \ldots\right) \delta^R \widehat{Y}\mu} = \frac{V^C L^C A^{CR} L^R L^R \delta^R \widehat{Y}\mu}{V^C L^C A^{CR} L^R \delta^R \widehat{Y}\mu} \tag{19}$$

From the above analysis, there appear to be situations in which regions and other countries participate in national production or global production at the same time. The final use corresponding to this part of the production is the final use brought about by the NGVC production $V^R L^R A^R (B_1 - B^{DR} \delta^R) \widehat{Y}\mu + V^R L^R A^{RC} B_2 \widehat{Y}\mu + V^C L^C A^{CF} B_2 \widehat{Y}\mu + V^C L^C A^{CR} (B_1 - L^R \delta^R) \widehat{Y}\mu$, denoted as yr_{ioe}. From the perspective of production outside the region, after weighing the number of production stages, the total input (wyr_{ioe}) caused by the NGVC production can be expressed as the difference of the total input caused by the production in the total value chain and the production in a pure value chain, which can be expressed as $V^R L^R A^R (B_1 B - B^{DR} B^{DR} \delta^R) \widehat{Y}\mu + V^R L^R A^{RC} B_2 B \widehat{Y}\mu + V^C L^C A^{CF} B_2 B \widehat{Y}\mu + V^C L^C A^{CR} (B_1 B - L^R L^R \delta^R) \widehat{Y}\mu$. Then, the average NGVC production length can be expressed as

$$plyr_{ioe} = \frac{wyr_{ioe}}{yr_{ioe}} \tag{20}$$

From different perspectives of production within and outside the region, the sum of the total input caused by the final use of the region is equal to the total input caused by the final use at the overall level. The accuracy of the backward decomposition results has been verified (see Appendix B).

2.1.3. *The position of production*

To measure the relative position of a country (or region) or sector in the national production network and the global production network, this paper draws on Wang et al.'s (2017) method and expresses the relative position of production as below:

$$posr_{Chains} = \frac{plvr_{Chains}}{(plyr_{Chains})'} \quad (21)$$

where $plvr_{Chains}$ and $plyr_{Chains}$ are forward and backward industrial linkages, the upstreamness and downstreamness are reflected. $Chains = \{All, Fin, VC, PNVC, PGVC, NGVC\}$ represents the overall, total intra-regional production, value chain production, pure NVC production, pure GVC production, and NGVC production, respectively. It can be seen from the above equation that the position index of production is closely related to the length of production, but the length of production does not necessarily reflect the position of a country (or region) or sector in production. The relative upstreamness can be calculated based on the ratio of the production length measured by the forward and backward industrial linkage. It can be seen from the above equation that the position index is closely related to the production length, and the production length cannot directly reflect the position of a country (or region) or sector in production. The relative upstreamness is calculated based on the ratio of production length measured by the forward and backward industrial linkages.

2.2. Data matching

To fully reflect the added value of various regions in China participating in different segments, this paper embeds the inter-regional input-output tables into the world input-output tables (Meng et al., 2017), and compiles an expanded inter-regional input-output tables that reflects the heterogeneity of regional and foreign trade. The data used includes three types: (1) the 2002 China Inter-Regional Input-Output tables (IRIOT) compiled by the Virtual Economy and Data Science Research Center of the Chinese Academy of Sciences, and the 2007, 2010, and 2012 China IRIOT compiled by the Key Laboratory of Regional Sustainable Development Analysis and Simulation of the Chinese Academy of Sciences. (2) The 2016 version of the World Input-Output Tables (WIOT) published by the World Input-Output Database (WIOD). (3) Chinese Customs' import and export data. Specifically, the compilation of the IRICIOT involves the following operations.

The sectoral differences between China's IRIOT and WIOD are unified into 18 sectors based on their definition. Consolidated final use is categorized into two categories: final consumption expenditure and total capital formation. As the harmonization system code (HS code) and national industries classification standards have been adjusted, the matching of HS codes and domestic sectors must be based on the correspondence table of all versions of the WITS database HS code and ISIC3, the correspondence table between different versions of the United Nations ISIC code, and the definition of each sector. The WIOD sector corresponds to the domestic sector. Intermediate products, final goods, and capital goods are classified according to the United Nations BEC code. Since WIOD uses basic prices,[1] and China's IRIOT are compiled using producer's prices,[2] it is necessary to adjust the prices of the WIOD in the process of connecting the two types of tables. As this paper mainly examines various Chinese regions' participation in domestic and global production, the data in China's IRIOT is used as the control. Customs import and export data and WIOD were then used to calculate ratio data and construct an expanded IRIOT. To ensure that the inter-regional relationship is not damaged, the intra-regional and inter-regional parts directly use the original IRIOT, and the other countries directly use the original data of other countries after price adjustments. The import and export use the customs proportion data, the WIOD proportion data, and the total value data of the IRIOT in its calculation. To ensure that there is a balance between the rows and columns, the results were constrained and optimized.

The result of IRICIOT can be seen in Table 1. Assuming that the table contains N ($N = 18$) sectors, S regions, and other G-1 (G-1=43) countries (or regions), countries that consider regional heterogeneity are called target countries. For the convenience of presentation, the superscript R is used to indicate each region in the country, and the superscript C is used to indicate country (or region). Among them, Z_{is}^{R} and Z_{ig}^{RC} reflect the intermediate use provided by region i to region s or country g. Y_{is}^{R} and Y_{ig}^{RC} are the corresponding final uses. Z_{mg}^{C} and Z_{mr}^{CR} reflect country m being in country g or region r. Y_{mg}^{C} and Y_{mr}^{CR} are corresponding final uses. X_{s}^{R} and X_{g}^{C} are the total output of region s and country g respectively, and Va_{s}^{R} and Va_{g}^{C} are the value added of region s and country g. According to the relationship between the various parts of the IRICIOT, the direct consumption coefficient matrix A can be obtained, wherein the quantity of products directly consumed by each industry unit production in region j is $A_{ij}^{R} = Z_{ij}^{R}(\widehat{X}_{j}^{R})^{-1}$, $\widehat{X}_{j}^{R}$ is the diagonal matrix of X_{j}^{R}. The global Leontief inverse matrix is $B = (I - A)^{-1}$, and I is the identity matrix of the same dimension as A. The value-added coefficient vector is $V = [V_{1}^{R}, \ldots\ldots, V_{S}^{R}, V_{2}^{C}, \ldots\ldots, V_{G}^{C}]' = [V^{R} \quad V^{C}]'$, where the value-added coefficient vector of region j is $V_{j}^{R} = Va_{j}^{R}(\widehat{X}_{j}^{R})^{-1}$.

3. Characteristics of production in the dual value chain

Based on the framework for measuring the position of the regional dual value chain proposed by this paper, the different production position is calculated to answer the question−where are the regions in China embedded in the production of dual value chain. Dialysis this question will help to clarify the China's role played in the dual value chain production, and also help enhance the status of Chinese regional dual value chain embeddings. According to the different levels of measurement, the position characteristics of China's dual

[1] Basic prices: The amount the producer receives from the purchaser per unit of goods or service produced, less the taxes on the products and plus any subsidies on the products. The basic price excludes transport costs invoiced separately.

[2] Producer's price: The producer's price is the amount receivable by the producer from the purchaser for a unit of a good or service produced as output minus any VAT, or similar deductible tax, invoiced to the purchaser; it excludes any transport charges invoiced separately by the producer.

Table 1
Regional embedded inter-country input-output tables (IRICIOT).

		Intermediate use						final use						Total out
		Region 1	…	Region s	Country 2	…	Country G	Region 1	…	Region s	Country 2	…	Country G	
Intermediate input	Region 1	Z_{11}^{R}	…	Z_{1s}^{R}	Z_{12}^{RC}	…	Z_{1G}^{RC}	Y_{11}^{R}	…	Y_{1s}^{R}	Y_{12}^{RC}	…	Y_{1G}^{RC}	X_{1}^{R}
	…	…	…	…	…	…	…	…	…	…	…	…	…	…
	Region s	Z_{s1}^{R}	…	Z_{ss}^{R}	Z_{s2}^{RC}	…	Z_{sG}^{RC}	Y_{s1}^{R}	…	Y_{ss}^{R}	Y_{s2}^{RC}	…	Y_{sG}^{RC}	X_{s}^{R}
	Country 2	Z_{21}^{CR}	…	Z_{2s}^{CR}	Z_{22}^{C}		Z_{2G}^{C}	Y_{21}^{CR}	…	Y_{2s}^{CR}	Y_{22}^{C}	…	Y_{2G}^{C}	X_{2}^{C}
	…	…	…	…	…	…	…	…	…	…	…	…	…	…
	Country G	Z_{G1}^{CR}	…	Z_{Gs}^{CR}	Z_{G2}^{C}	…	Z_{GG}^{C}	Y_{G1}^{CR}	…	Y_{Gs}^{CR}	Y_{G2}^{C}	…	Y_{GG}^{C}	X_{G}^{C}
Value Added	Va_{1}^{R}		…	Va_{s}^{R}	Va_{2}^{C}	…	Va_{G}^{C}							
Total input	$X_{1}^{R}{'}$		…	$X_{s}^{R}{'}$	$X_{2}^{C}{'}$	…	$X_{G}^{C}{'}$							

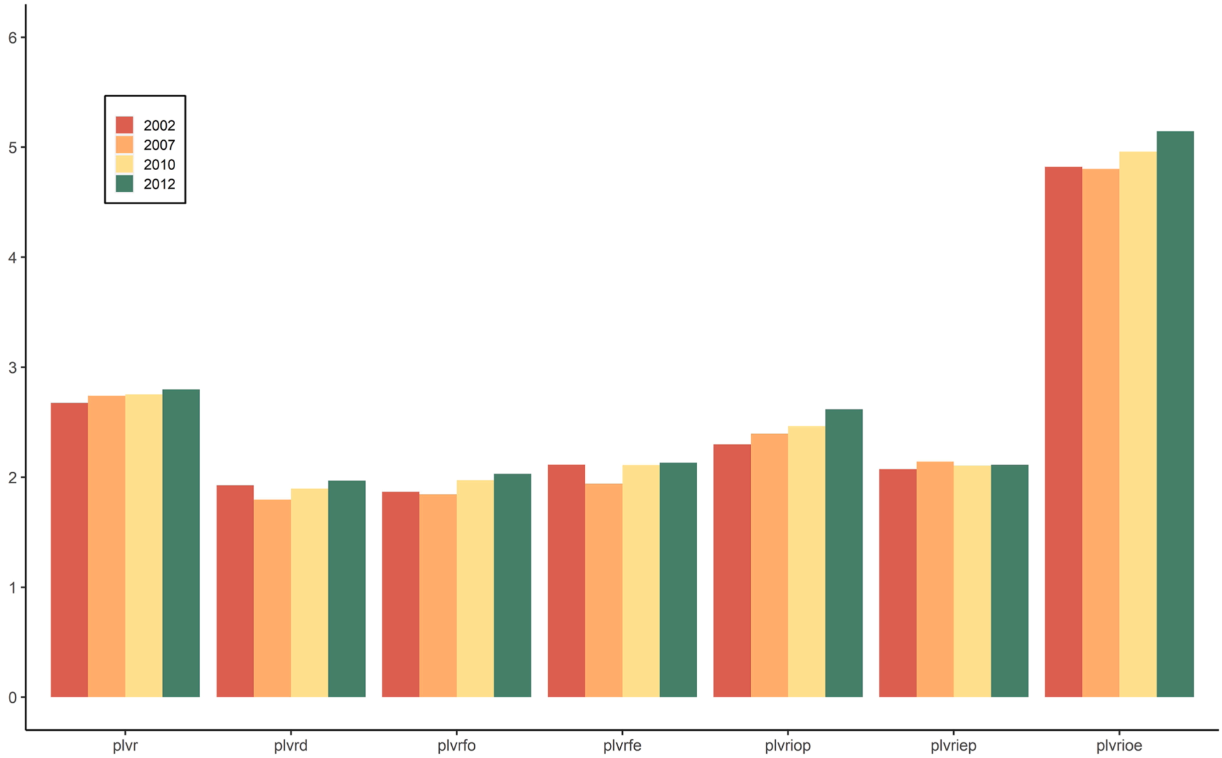

Fig. 3. Forward industrial linkage in different segments.

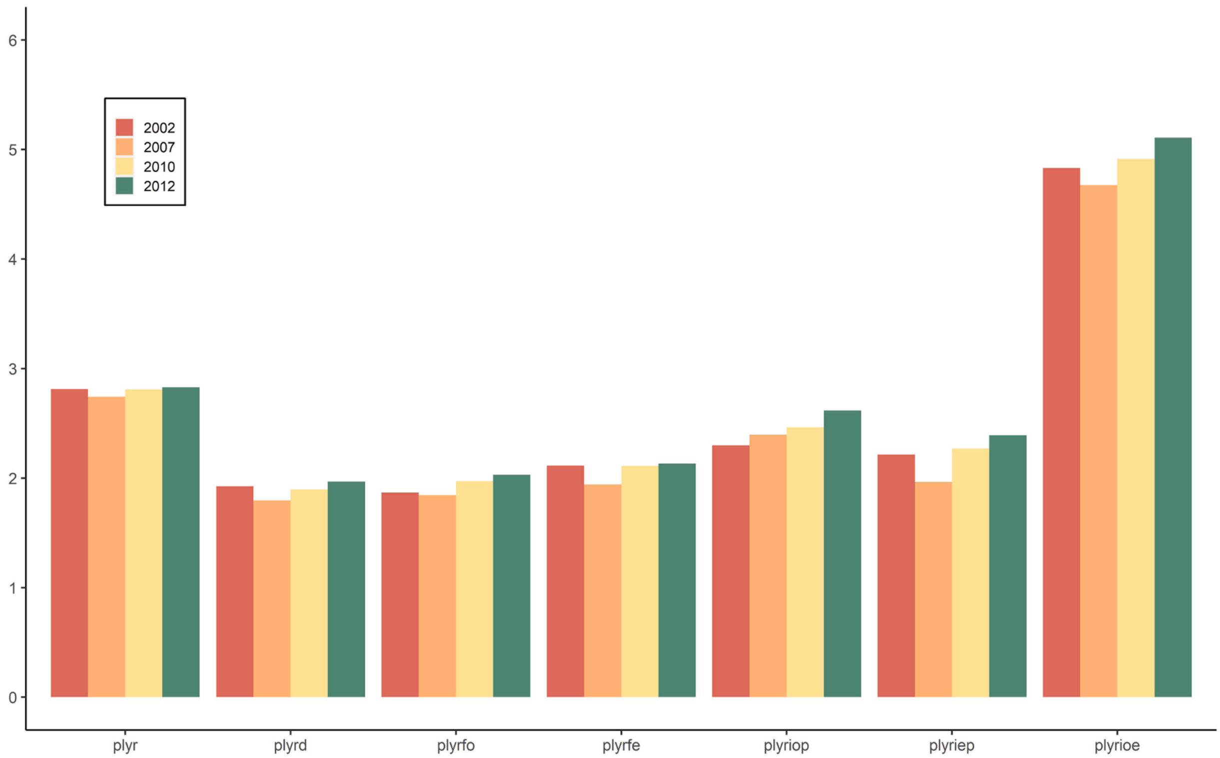

Fig. 4. Backward industrial linkage in different segments.

Table 2
Relative production positions at the overall level.

Patterns of production			2002	2007	2010	2012
Total relative position	All patterns of production	$posr_{ALL}$	0.9508	0.9990	0.9795	0.9893
Relative position of total intra-regional production	Intra-regional production	$posr_{d}$	1.0000	1.0000	1.0000	1.0000
	Inter-regional final goods trade	$posr_{fo}$	1.0000	1.0000	1.0000	1.0000
	Regional-international final goods trade	$posr_{fe}$	1.0000	1.0000	1.0000	1.0000
Relative position of a pure NVC production		$posr_{PNVC}$	1.0000	1.0000	1.0000	1.0000
Relative position of a pure GVC production		$posr_{PGVC}$	0.9356	1.0899	0.9277	0.8827
The relative position of the NGVC production		$posr_{NGVC}$	0.9978	1.0274	1.0095	1.0073

Fig. 5. Changes in the relative positions of pure NVC production and NGVC production in China. *Notes*: The horizontal axis shows the changes in the relative position of pure NVC production between 2002 and 2007 and 2007–2012, and the vertical axis shows the changes in the relative position of NGVC production in the corresponding period. The first quadrant indicates that the relative positions of the two value chains increased at the same time. The second quadrant indicates that while the relative position of the pure NVC production decreased, the relative position of the NGVC production increased. The third quadrant indicates that the relative positions of the two value chains decreased simultaneously. The fourth quadrant indicates that while the relative position of the production in pure NVC rose, the relative position of the production in NGVC decreased.

value chain can be analyzed from the national, regional, sectoral, and regional sectoral levels.

3.1. National level

The different production length based on the forward and backward industrial linkage is shown in Figs. 3 and 4. The results show that the total average production length is about 2.80. Compared with the total average production length, the average production length of total intra-regional production is lower. The average production length of NGVC production is much higher than pure value chain production. Value chain production and other patterns of production have the highest upstreamness and downstreamness. In terms of time, the average production length of most production has an upward trend.

The upstreamness index and downstreamness index calculated by the forward industrial linkage and the backward industrial linkage are used to calculate the relative position of different patterns of production. According to the calculation method of the relative position of production, the results are shown in Table 2. The relative position index of the overall level of each region is less than 1, which shows that from the perspective of China as a whole. China is in a relatively downstream position, which is consistent with the conclusion of Wang et al. (2017). The relative position index of a pure GVC production is less than 1 except for in 2007. The NGVC production is relatively upstream, and the position index is basically greater than 1. Generally speaking, although China's

Fig. 6. Changes in the relative positions of pure GVC production and NGVC production in China's regions. *Notes*: The horizontal axis shows changes in the relative position of pure GVC production between 2002 and 2007 and 2007–2012, and the vertical axis shows changes in the relative position of NGVC production in the corresponding period.

overall level is relatively downstream, NGVC production is relatively upstream. From the perspective of production outside the region, the relative position indices of pure GVC production and NGVC production have shown a trend of first increasing and then decreasing over time.

3.2. Regional level

The changes in the relative positions of pure NVC production and the NGVC production in each region in 2002, 2007, 2010, and 2012 (Fig. 5), and the changes in the relative positions of pure GVC production and NGVC production (Fig. 6) were analyzed to determine the evolution of the relative position of production in the pure value chain, as well as production in the dual value chain (more detail see Appendix C and D).[3]

It can be seen from Fig. 5 that during the period of 2002–2007, the relative position of most regions in China gradually moved to a relatively upstream position in NGVC production, in particular, Jilin, Shanxi, Xinjiang, Gansu, Shaanxi, Yunnan, Qinghai, Gansu, Ningxia, Inner Mongolia, and other central and western regions. At the same time, these regions gradually moved to relatively upstream positions in pure NVC production. This shows that NGVC production and pure NVC production effectively coordinated the participation of the central and western regions. In NGVC production and pure NVC production, the central and western regions placed their attention on their own resource advantages, and the role of raw material and primary product suppliers became more prominent, and thereby they were closer to the relative upstream position of NGVC production. Shanghai, Shandong, Liaoning are in the third quadrant, with more backward participation in NGVC production and pure NVC production, where the role of processing manufacturers is more prominent. On the whole, in NGVC production, the relative position of the production of central and western regions increased significantly, while the increase in the eastern and coastal regions was smaller (or non-existent in some regions). This shows that integration into the dual value chain production is conducive to breaking the domestic market segmentation and coordinating regional production. The eastern and coastal regions make full use of the central and western resources for production, while also promoting the use of the western region's resource advantages.

During the period of 2007–2012, the relative position of NGVC production declined in some regions of China such as Guangdong,

[3] Shorthand for each region of China：Anhui (AH), Peking (BJ), Fujian (FJ), Gansu (GS), Guangdong (GD), Guangxi (GX), Guizhou (GZ), Hainan (HI), Hebei (HE), Henan (HA), Heilongjiang (HL), Hubei (HB), Hunan (HN), Jilin (JL), Jiangsu (JS), Jiangxi (JX), Liaoning (LN), Inner Mongolia (NM), Ningxia (NX), Qinghai (QH), Shandong (SD), Shanxi (SX), Shaanxi (SN), Shanghai (SH), Sichuan (SC), Tianjin (TJ), Xinjiang (XJ), Yunnan (YN), Zhejiang (ZJ), Chongqing (CQ). Due to the serious lack of data on Tibet, Tibet has not been included in the analysis.

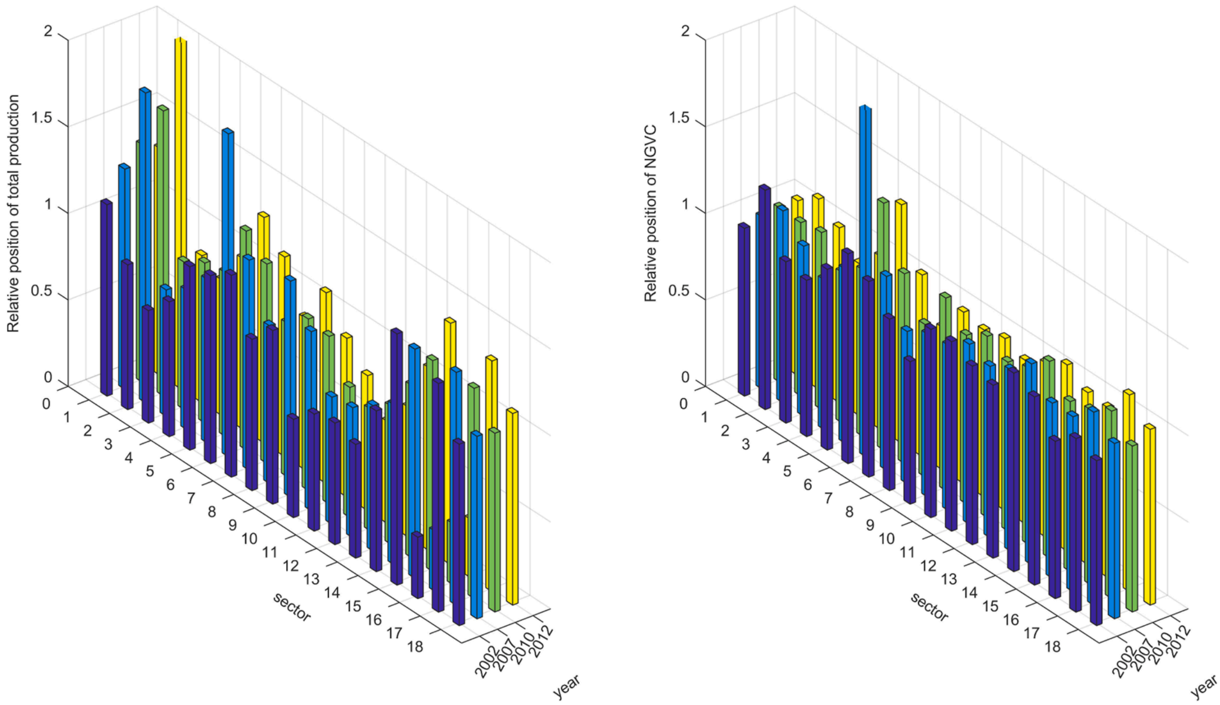

Fig. 7. The relative position of production in various sectors across China. *Notes*: The figure on the left shows the total relative production positions of all production in each sector across the different years. The figure on the right indicates the relative position of NGVC production.

Beijing, Shanghai, Shandong, Tianjin, Liaoning, Shandong, Hebei, and other eastern and coastal regions. Part of the central and western regions, such as Gansu, Qinghai, Ningxia, Jiangxi, and Anhui, have shifted their participation in NGVC production to a relatively downstream position. From the perspective of the composition of NGVC production, this could be because more intermediate products are imported from other regions (often for processing and production), and then exported abroad or to other regions for further production. The development of NGVC production has gradually allowed more regions to participate in the production and processing linkage, so that the role of most regional production has gradually changed from raw materials and primary product suppliers to processing manufacturers. From the perspective of pure NVC production, central and western regions such as Inner Mongolia, Xinjiang, Shanxi, and Yunnan continue to move to relatively upstream positions, while the eastern and coastal regions such as Shanghai, Tianjin, Shandong, and Liaoning continue to move to relatively downstream positions. This shows that NGVC production has effectively promoted the adjustment of pure NVC production on the regional level.

It can be seen from Fig. 6 that during the period of 2002–2007, most regions were concentrated in the first quadrant (that is, the positions of these regions in both pure GVC production and NGVC production improved). This shows that during the period 2002–2007, whether China participated in pure GVC production or NGVC production, it was mainly in terms of supplying raw materials and primary products.

During the period of 2007–2012, the situation of participating in pure GVC production in various regions underwent major changes. The position of participating in pure GVC production declined significantly in most regions, and all of them shifted to relatively downstream positions. The relative position of NGVC production in the eastern coastal region also reflects this. This shows that during the period of 2007–2012, when each region of China participated in pure GVC production, most of them focused on processing and manufacturing, and they were relatively downstream in the production chain. Although regions such as Inner Mongolia, Guizhou, Hunan, Xinjiang, Shanxi, and Yunnan declined in pure GVC production, NGVC production gradually shifted to a relatively upstream position. This shows that the NGVC production can avoid the low-end lock-in problem caused, to some extent, by excessively pursuing pure GVC production. When most regions in China are locked in the middle and downstream processing and manufacturing linkage of pure GVC production, the NGVC production can provide a solution for this dilemma. Therefore, it is necessary to give full play to the resource endowment advantages of the central and western regions, and utilize the manufacturing advantages of the eastern and coastal regions. Furthermore, it is of utmost importance to strengthen the role of suppliers of raw materials and primary products in the central and western regions, as well as the role of processing manufacturers in the eastern and coastal regions. In this way, each region could use its strengths to coordinate regional development.

3.3. Sector level

As can be seen from the left side of Fig. 7, primary product sectors such as agriculture, forestry, animal husbandry and fishery,

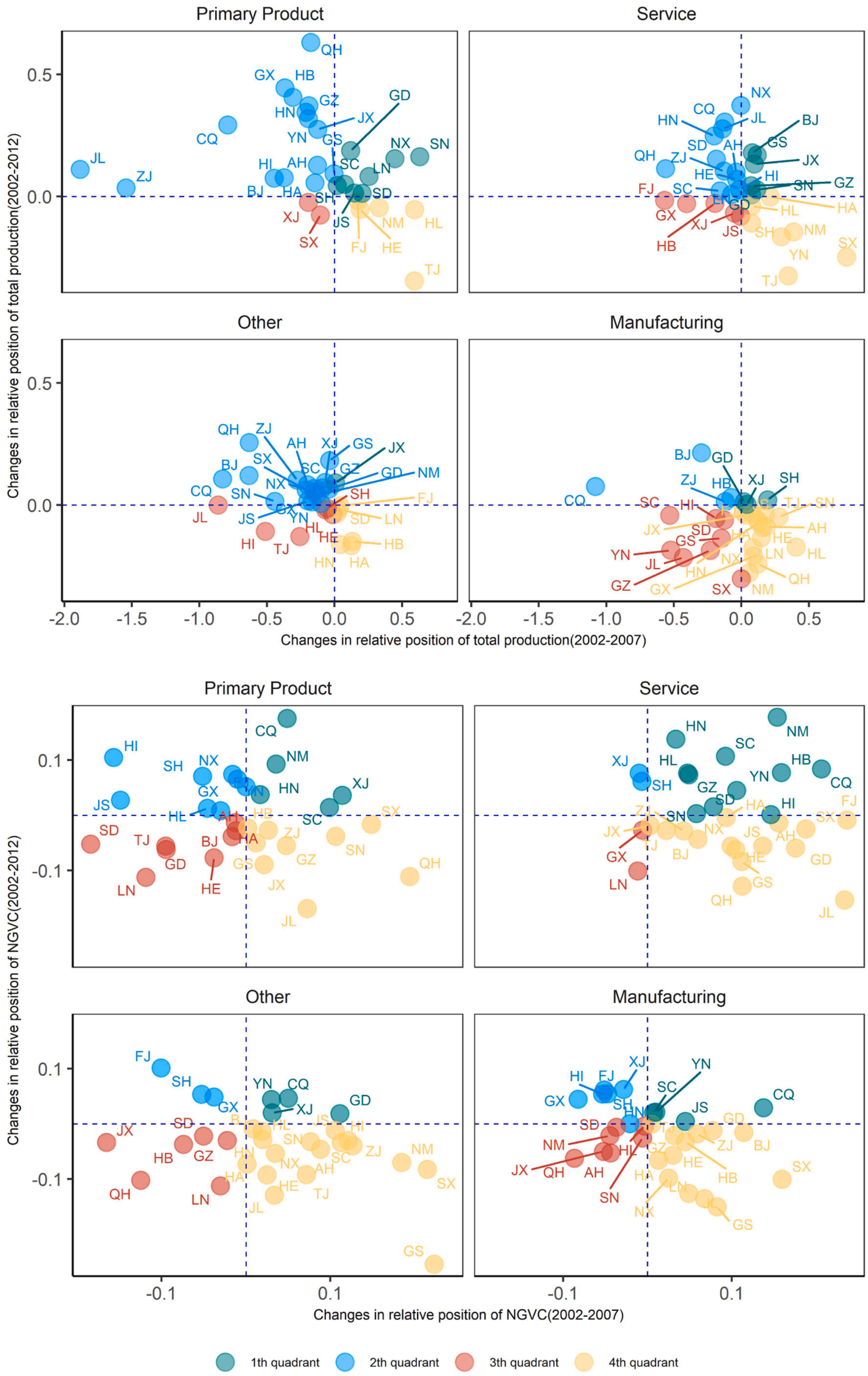

Fig. 8. Changes in the relative positions of various sectors and regions in China from 2002 to 2012. *Notes*: The horizontal axis represents the relative position change from 2002 to 2007, the vertical axis represents the relative position change from 2007 to 2012, and the dotted line in the figure is the critical value of the relative position change.

extractive industries, and low-tech manufacturing sectors such as textiles/garments and wood products, all have a relatively large relative position index that is greater than 1 (that is, they are relatively upstream in production). The construction and manufacturing sectors such as general equipment and transportation equipment are less than 1, especially the construction sector. The relative position index of all sectors is the smallest, which is relatively downstream. From the perspective of different years, the relative position index of most sectors increased in 2007 and moved to a relatively upstream position. It decreased in 2010 and rebounded slightly in 2012. From the right side of Fig. 7, the relative position of NGVC production varies slightly between sectors at the overall level.

Regardless of the overall level or NGVC production, it can be posited that most of China's manufacturing and construction sectors are relatively downstream in the fragmentation of production. For construction, a large number of intermediate products need to be used for production before entering the consumer market, and it has experienced many production linkages, so it is in a relatively downstream position. China's manufacturing industry is also in a relatively downstream position, which shows that China's participation in production mostly occurs in the value chain in the form of import (inflow)-processing production-export (outflow), occupying the middle and low-end production process. The primary product sector and some low-tech manufacturing sectors play a more important role in production by providing raw materials or intermediate products to other sectors, so they are relatively upstream. Compared with 2010, the relative position of most sectors in 2012 moved upstream on the overall level, and the trend of NGVC production is not obvious.

Considering all the production methods, the relative production position only considering NGVC does not show a bifurcated character. The reason is that the connotations of the two relative production positions are different, considering that all the production includes national production and transnational production, the manufacturing sector and other industrial sectors tend to use a large number of intermediate inputs from other sectors, and immediately enter the consumer market after production as the final product, and the distance from the final demand is very short. When only considering the NGVC production, this production involves both interregional production and global value chain production, at this time, the manufacturing sector and other industrial sectors will not only use a large number of intermediate inputs from other sectors, but will further be produced as intermediate inputs from other countries, and finally produce as final products and indirectly enter the consumer market. Since the NGVC production considers both the interregional production and the global value chain production, the relative position difference between departments no longer shows a bifurcated character.

3.4. Regional sector level

Due to the huge impact of the global financial crisis that occurred in 2007–2009, this paper uses 2007 as the demarcation point to analyze the changes in the average relative position of the overall level and the relative position of NGVC production. Fig. 8 is drawn with the relative position change from 2002 to 2007 as the horizontal axis, and the relative position change from 2007 to 2012 as the vertical axis.[4]

For the manufacturing sectors, the total relative position of most eastern and coastal regions did not change much in the period of 2002–2007. During 2007–2012, the relative positions of most regions decreased, moving to a relatively downstream position, which is quite different from the changes in the primary product sectors. From the perspective of the relative position of NGVC production, most regions were clustered near the origin, and the relative position did not change much in terms of participating in NGVC production. During the period of 2002–2007, Shanxi, Chongqing, Beijing, Guangdong, Jiangsu, and other regions gradually moved to relatively upstream positions, while Guangxi, Qinghai, and other regions moved to relatively downstream positions. During the period of 2007–2012, the relative position index of Fujian, Hainan, Shanghai, and other regions increased and gradually shifted to relatively upstream positions, while the central and western regions such as Gansu, Shanxi, and Ningxia gradually shifted to relatively downstream positions.

In summary, China took advantage of its labor advantage to undertake some industrial transfers from developed countries before the crisis. At the same time, its active opening up made China face huge foreign market demand. Under the international circulation of supply and demand, the relative position of service sectors in various regions of China to participate in NGVC production has improved. After the crisis, coupled with the spread of the anti-globalization trend, the total relative position of the manufacturing sectors in most regions gradually moved to a relatively downstream position, locked in the middle-low end production process. However, in NGVC production this was not the case. Nearly half of the region moved to a relatively upstream position, breaking through the predicament of low-end lock-in. This shows that for the manufacturing sectors, participation in value chain trade in the form of simple production such as a pure value chain is more affected by the external environment, and its ability to resist risks is relatively weak. The NGVC production has less of a negative impact, it can enable some regions to break free from the shackles of low-end locks and move to relatively upstream positions in the value chain.

[4] Primary product sectors : 1-Agriculture, forestry, animal husbandry and fishery; 2-extractive industry; Manufacturing sectors: 3- Food processing, 4- textile and garment industries, 5- wood products, 6- fuel processing, 7- chemical products, 8- non-metal products, 9- metal processing, 10- metal products, 11- General equipment industry, 12- transportation equipment, 13- electrical machinery industry, 14- electronic communications industry. Other sectors : 15- energy sector, such as hydropower, 16- Construction; Service sectors: 17- Transportation, warehousing and postal services, 18- Services.

4. Empirical approach

International economic and trade frictions and regional development imbalance have made China's economic growth impetus apparently insufficient, so that China urgently needs to seek new impetus to maintain economic growth. Krugman (1994) and Krugman (2000) pointed out that the long-term economic growth of a country can be attributed to two aspects: one is the increase in factor input, and the other is the increase in factor productivity, that is, the increase in labor productivity or total factor productivity. Economic growth that relies solely on factor input expansion at the cost of extensive consumption of factors and resources is unsustainable in the long run. Only by increasing total factor productivity (TFP) can the sustainability of economic growth be ensured. Technological progress is an important part of total factor productivity and an important indicator that reflects a country's domestic growth capacity. Then, whether technological progress, as an important driving force of a country's economic growth, will affect the transformation of the production in the dual value chain in the process of promoting economic growth, and thus produce a marginal contribution to economic growth, remains to be further studied.

The basis of production in the value chain is comparative advantage. Technological progress will inevitably affect the distribution and utilization of resource elements by production units, thereby changing the comparative advantages of products, industries and regions in different regions, and prompting each region to dynamically adjust according to its own comparative advantages. The production division strategy is to ensure the maximization of self-interest, so that different production division links can be re-allocated on a national or global scale, thereby changing the dual value chain production in different regions.

Throughout previous studies, a large number of reviews have been analyzed from the perspective of value chain embedding affecting technological progress. Most documents believe that value chain embedding affects technological progress through category effects, quality effects and technology spillover effects (Ethier, 1982; Rivera-Batiz, Romer, 1991; Alviarez, 2019). However, from the perspective of technological progress, only a few scholars have studied the development of a particular technology (Pascali, 2017), the rebound effect caused by technological progress (Chen et al., 2020a), the carbon emission effect of technological progress (Chen et al., 2020b), the quality improvement brought about by technological progress (Bas & Strauss-Kahn, 2015) has studied the impact of technological progress on economic development. There are few literatures directly studying the impact of technological progress on the embeddedness of the value chain. Therefore, this section conducts a multi-perspective analysis of this issue to fill the gaps in existing research.

4.1. Variable description and data

The explained variable is the position of the value chain under different segments, and the core explanatory variable is technological progress. The growth of TFP ($\dot{TFP}_{pst}$), measured by the stochastic frontier analysis.

The control variables at the regional level are: (1) the mileage of expressways in each region. The expressway is an important channel linking the production and product transportation between regions. The longer the expressway mileage, the lower the time cost of production and trade. (2) The reciprocal of the distance from each region to the port, since the port is an important channel for trade between China's various regions and the international market. The farther away from the port, the higher the trade cost. (3) County economic gap and market segmentation. The county economic gap is calculated by calculating the ratio of GDP from each region to the county-level boundary, and controlling it to be between 0 and 1. The larger the value, the smaller the regional economic gap. The degree of market segmentation is calculated with reference to the price method of Parsley and Wei (1996, 2001). The increase in trade costs between regions will make the international market play a substitute role for domestic products, thereby affecting global production. The sectoral level controls industrial concentration and is used to measure industrial competitiveness and monopoly. Research shows that industrial concentration will have the opposite impact on technological innovation through scale and competition effects (Schumpeter, 1942; Acs & Audretsch, 1988).

The control variables of regional sector level control are: (1) production input related indicators, such as total fixed assets, number of employees, and average wage level. (2) The average age of an enterprise that reflects the development maturity of the sector (the current year minus the year of business opening + 1). The age of the enterprise may affect the production and trade behavior of the sector through age and intergenerational effects. (3) The subsidy income reflects the degree of government support. A large number of studies have shown that subsidy income has a significant impact on exports and the quality of export products. To alleviate the possible heteroscedasticity problem, all variables are logarithmic.

The above variables are calculated based on the following data. The position of the value chain is calculated using the IRICIOT compiled in this paper. The control variables at the regional level are derived from the official website of the National Bureau of Statistics in China. The control variables at the technological progress, sectoral, and regional sector level are calculated based on the Chinese industrial enterprise database. As previously mentioned, the sample covered 2002, 2007, 2010, and 2012. The regional level involves 30 provinces, municipalities, and autonomous regions in China, and Tibet was excluded from the sample due to the lack of data available. The sectoral level involves 14 sectors such as mining and selection industries and manufacturing, but not all regions have exported in all sectors, and there are data abnormalities. Therefore, the final balanced panel data is 1088 samples.

4.2. Model design

In this paper, the Bayesian model averaging method was used for estimations. For any candidate model *M*, its shape is set. Eq. (22) is as follows.

Table 3
Benchmarking regression results.

Variables	Value chain production			Pure GVC production			Pure NVC production			NGVC production		
Explained variable: $posr_{l,pst}$	PIP	Post Mean	Post SD	PIP	Post Mean	Post SD	PIP	Post Mean	Post SD	PIP	Post Mean	Post SD
$\dot{TFP}_{pst}$	0.1502	-0.0055	0.0182	0.9212	-0.1056	0.0444	0.0567	-0.0027	0.0134	0.0497	-0.0018	0.0113
Industrial concentration	1.0000	0.2213	0.0263	1.0000	0.1983	0.0262	1.0000	0.1363	0.0236	1.0000	0.2050	0.0318
Total fixed assets	0.9955	0.2651	0.0667	0.9761	-0.2074	0.0486	0.0581	0.0054	0.0265	0.4325	-0.0958	0.1194
Number of employees	1.0000	-0.4121	0.0632	0.0728	-0.0066	0.0354	1.0000	-0.3144	0.0360	0.6818	-0.1572	0.1170
Average salary	0.9997	0.1642	0.0344	0.9976	0.1758	0.0397	1.0000	0.2793	0.0270	1.0000	0.2176	0.0516
Average firm age	0.9996	-0.1159	0.0250	1.0000	-0.1643	0.0269	0.0217	0.0002	0.0040	0.9514	-0.0911	0.0325
subsidy income	0.8548	-0.0872	0.0475	0.0455	0.0006	0.0080	0.0538	-0.0026	0.0133	0.1153	-0.0069	0.0226
Highway mileage	0.9996	-0.1376	0.0290	1.0000	-0.2241	0.0331	0.9900	-0.1144	0.0299	0.9977	-0.1366	0.0316
1/ (Distance to port)	0.3278	-0.0138	0.0235	0.2936	-0.0150	0.0265	0.0230	-0.0003	0.0038	0.0748	-0.0025	0.0109
County economic gap	0.9646	-0.0778	0.0272	0.0582	-0.0012	0.0076	0.0680	-0.0025	0.0111	0.0458	0.0011	0.0072
Market segmentation	0.1171	0.0026	0.0121	0.1297	0.0062	0.0194	0.0215	-0.0002	0.0045	0.0293	0.0001	0.0052
Constant	1.0000	8.6741	–	1.0000	7.7588	–	1.0000	7.6251	–	1.0000	13.0515	–

Table 4
Replacing the robustness test of core explanatory variables.

Variables	Value chain production			Pure GVC production			Pure NVC production			NGVC production		
Explained variable: $posr_{l,pst}$	PIP	Post Mean	Post SD	PIP	Post Mean	Post SD	PIP	Post Mean	Post SD	PIP	Post Mean	Post SD
$\dot{TFP}'_{pst}$	0.0930	0.0011	0.0103	0.5848	-0.0524	0.0507	0.0204	-0.0001	0.0047	0.0329	-0.0005	0.0068
Constant	1.0000	8.6826	–	1.0000	7.7514	–	1.0000	7.6231	–	1.0000	13.0530	–
Control variables	Yes			Yes			Yes			Yes		

$$Vchain_{l,pst} = \alpha_0 + \beta_1 * \dot{TFP}_{pst} + \beta_2 * control_{pt} + \beta_3 * control_{st} + \beta_4 * control_{pst} + \varepsilon_{pst} \qquad = \beta_k X_k + \varepsilon_{pst} \tag{22}$$

where p is the region, s is sector, t is the time, $\dot{TFP}_{pst}$is the growth of TFP to reflect technological progress, and $Vchain_{l,pst}$ represents the value chain embedding of the l type of production. $l = \{VC, PGVC, PNVC, NGVC\}$ respectively represent the production in the value chain, pure GVC, pure NVC, and NGVC production. $control_{pt}, control_{st}, control_{pst}$ respectively represent the control variables at the time-region, time-sector, and time-region-sector level. ε_{pst} represents a random error term, and $\alpha_0, \beta_1, \beta_2, \beta_3, \beta_4$ are parameters to be estimated. The vector composed of all parameters to be estimated is β_k, and the variable set composed of $\dot{TFP}_{pst}$and the control variables of each level is X_k.

This paper adopts the Bayesian model averaging (BMA) method to estimate the posterior mean (Post Mean), posterior standard deviation (Post SD), and posterior probability (PIP) of model based on the prior distribution of model parameters. This paper adopts $R_{4.2.1}$ software, the *bms* function in the BMS package is used for analysis, and the parameter settings are set by the default. The model prior choice defaulting to "random", the hyperparameter on Zellner's g-prior for the regression coefficients, $g = "UIP"$. The MC3 sampler is the model sampler, $mcmc = "bd"$. The BMA method overcomes the uncertainty of the results when regressing on a given set of explanatory variables from the selection of explanatory variables, model selection, and model synthesis. Therefore, this paper used this method to analyze the path of influence of technological progress on the position of the value chain.

5. Empirical analysis

From the perspective of technological progress, this section analyzes the impact of technological progress on the dual value chain position, and recalculates the technological progress and the dual value chain position. The results are tested for the robustness of replacing the core explanatory variables and replacing the explained variables to verify the robustness of the results. Taking into account the development differences between different regions, the differences in the roles of different departments in the production, and the differences in the global production before and after the crisis. It further analyzes the heterogeneity of the impact of technological progress on the position of the dual value chain at the regional level, sector level, and before and after the crisis.

5.1. Benchmarking analysis

To explore the impact of technological progress on the position of the value chain, a regression model is used for empirical analysis, and the results are shown in Table 3. It can be shown that for different types of value chain productions, the following relationship exists between technological progress and the position of the value chain. The PIP and Post Mean value of technological progress on pure GVC production position are 0.9212 and $-$ 0.1056, respectively, which indicates that the impact of technological progress on the relative position of value chain production is mainly concentrated on pure GVC production, and the direction of influence is negative (that is, technological progress will cause regional sectors to participate in pure GVC production, thereby moving towards a more downstream position). The production transmitted to the overall value chain has a slight negative impact. For the relative production position in other value chains, the impact of technological progress is not obvious.

5.2. Robustness test

5.2.1. Replace core explanatory variables

Based on the realistic background of overcapacity in China, and drawing on the ideas of Basu, Fernald and Kimball (2006), the estimated technological progress ($\dot{TFP}'_{pst}$) was calculated after considering capacity utilization, and analyzing its impact on the position of production in different value chains. From the result, the impact of technological progress in consideration of capacity utilization on the position of the value chain is mainly concentrated on pure GVC production. Technological progress will push the pure GVC production to a relatively downstream position. The impact on other types and the total value chain position is not obvious. This finding is consistent with the benchmark analysis, the results of which are robust (see Table 4).

5.2.2. Replace the explained variable

To further verify the robustness of the results, the value chain position index was reconstructed, and the ratio of upstreamness and downstreamness was replaced with the difference between them to reflect each regional sector from the perspective of relative

Table 5
Replacing the robustness test of the explained variable.

Variables	Value chain production			Pure GVC production			Pure NVC production			NGVC production		
Explained variable: $posr_{l,pst}'$	PIP	Post Mean	Post SD	PIP	Post Mean	Post SD	PIP	Post Mean	Post SD	PIP	Post Mean	Post SD
$\dot{TFP}_{pst}$	0.1052	-0.0035	0.0150	0.9570	-0.1159	0.0409	0.0480	-0.0021	0.0118	0.0516	-0.0021	0.0120
Constant	1.0000	1.5476	–	1.0000	2.8251	–	1.0000	1.0025	–	1.0000	1.8044	–
Control variables	Yes			Yes			Yes			Yes		

upstreamness and downstreamness. The specific calculation formula is as follows.

$$posr_{l,pst}' = \frac{plvr_{l,pst} - plyr_{l,pst}}{plvr_{l,pst} + plyr_{l,pst}} \tag{23}$$

Where $posr_{l,pst}'$ is the new relative position index, $plvr_{l,pst}$ is the 'upstreamness' and $plyr_{l,pst}$ means the downstreamness (the meaning of superscripts and subscripts is consistent with previous descriptions in the text). The robustness test results of the replacement value chain position index show that technological progress has an important negative impact on pure GVC production in Table 5 (that is, technological progress will cause various regional departments to move to a relatively downstream position when participating in pure GVC production). The impact of this on the pure NVC and NGVC production is not obvious, but the final conclusion is that it has a small negative impact on the total value chain production. This is again consistent with the benchmark analysis, and the robustness of the benchmark analysis has been verified.

5.3. Heterogeneity analysis

5.3.1. Discussion by region

To explore the regional heterogeneity of the influence of technological progress on the embedding positions of different types of value chains, this paper analyzes the eastern, central, and western regions, respectively, and the results are shown in Table 6.

It can be found that technological progress has a positive impact on production in different types of value chains in the eastern region of China, but the degrees of influence vary. The PIP and Post Mean of the NGVC production are more than that of pure NVC, and the PIP and Post Mean of pure NVC are more than that of pure GVC. The final impact of technological progress will promote the shift of the position of the value chain in the eastern region to a relatively upstream position. It's the opposite of the eastern region, technological progress has a negative impact on production in different types of value chains in the central region. The relationship between the PIP and Post Mean value of different types of value chains is consistent with the eastern region. The final impact of technological progress will promote the shift of the position of the value chain in the central region to a relatively downstream position. Similarly, technological progress has a negative impact on pure GVC production in the western region, but this impact is not significant. Finally, the effect of technological progress on the total value chain production position is negative and not significant in the western region.

5.3.2. Discussion by sector

According to the OECD's technology-intensive classification standards for manufacturing, as well as China's high-tech industry (manufacturing) classification (2017), the sector is divided into high-tech manufacturing sectors and other sectors. Among them, the high-tech manufacturing sector includes chemical products, electrical machinery, electronic communications, and other sectors. The analysis results on sectoral heterogeneity in terms of the impact of technological progress on the positions of production in different types of value chains are shown in Table 7.

The negative impact of technological progress on the position of the value chain of the high-tech manufacturing sector is mainly concentrated on pure NVC production. The final manifestation is that technological progress has a small negative impact on the position of the high-tech manufacturing sector's total value chain production, prompting it move to a relatively downstream position. The negative impact of technological progress on the position of the value chain of other departments is mainly concentrated in the pure GVC production, which promotes pure GVC production in other sectors to move relatively downstream; the impact on the position of pure NVC production and the NGVC production is not obvious. The final negative impact on the production in the total value chain of other departments is not obvious.

5.3.3. Discussion by period

From the analysis on characteristics of production in the dual value chain, it can be seen that domestic and foreign production underwent certain changes before and after the crisis, especially the production in the GVC, which was particularly affected by the crisis. To analyze the heterogeneity of the impact of technological progress on the positions of different types of value chains, the samples were further divided into two groups, 2002–2007 and 2010–2012 (that is, before and after the crisis), and the results are shown in Table 8.

The result shows that the influences of technological progress on the total value chain production, the production in pure GVC, and the production in pure NVC increased after the crisis. After the crisis, technological progress promoted total value chain production

Table 6
Regression results by region.

Variables		Value chain production			Pure GVC production			Pure NVC production			NGVC production		
Explained variable: $posr_{l,pst}$		PIP	Post Mean	Post SD	PIP	Post Mean	Post SD	PIP	Post Mean	Post SD	PIP	Post Mean	Post SD
Eastern region	$\dot{TFP}_{pst}$	0.4366	0.0526	0.0697	0.1117	0.0060	0.0256	0.2088	0.0211	0.0471	0.4024	0.0481	0.0679
	Constant	1.0000	7.3601	–	1.0000	9.0507	–	1.0000	6.8576	–	1.0000	13.3210	–
Central region	$\dot{TFP}_{pst}$	0.5792	-0.0942	0.0998	0.6394	-0.1334	0.1230	0.8639	-0.1845	0.0990	0.9211	-0.2009	0.0865
	Constant	1.0000	10.1211	–	1.0000	7.8661	–	1.0000	9.3576	–	1.0000	14.2483	–
Western region	$\dot{TFP}_{pst}$	0.0611	-0.0036	0.0218	0.4022	-0.0580	0.0805	0.0227	-0.0003	0.0099	0.0299	0.0006	0.0128
	Constant	1.0000	9.0142	–	1.0000	7.2051	–	1.0000	8.3766	–	1.0000	14.1373	–
Control variables		Yes			Yes			Yes			Yes		

Table 7
Regression results by sector.

Variables		Value chain production			Pure GVC production			Pure NVC production			NGVC production		
Explained variable: $posr_{l,pst}$		PIP	Post Mean	Post SD	PIP	Post Mean	Post SD	PIP	Post Mean	Post SD	PIP	Post Mean	Post SD
High-tech manufacturing sector	$\dot{TFP}_{pst}$	0.1030	-0.0103	0.0367	0.0653	-0.0040	0.0219	0.9574	-0.2226	0.0780	0.0688	-0.0054	0.0267
	Constant	1.0000	12.3113	–	1.0000	12.3306	–	1.0000	9.7691	–	1.0000	17.1519	–
Other sectors	$\dot{TFP}_{pst}$	0.0361	-0.0012	0.0095	0.9855	-0.1377	0.0395	0.0208	0.0000	0.0055	0.0444	-0.0020	0.0122
	Constant	1.0000	7.6622	–	1.0000	7.5851	–	1.0000	7.5955	–	1.0000	12.7887	–
Control variables		Yes			Yes			Yes			Yes		

Table 8
Regression results by periods.

Variables		Value chain production			Pure GVC production			Pure NVC production			NGVC production		
Explained variable: $posr_{l,pst}$		PIP	Post Mean	Post SD	PIP	Post Mean	Post SD	PIP	Post Mean	Post SD	PIP	Post Mean	Post SD
2002–2007	$\dot{TFP}_{pst}$	0.0372	-0.0010	0.0118	0.0489	-0.0032	0.0173	0.0412	-0.0014	0.0125	0.0710	0.0049	0.0240
	Constant	1.0000	7.2141	–	1.0000	5.5298	–	1.0000	7.1126	–	1.0000	11.1431	–
2010–2012	$\dot{TFP}_{pst}$	0.1171	0.0070	0.0225	0.1984	-0.0148	0.0339	0.1657	0.0105	0.0278	0.0443	0.0020	0.0121
	Constant	1.0000	9.1575	–	1.0000	9.2376	–	1.0000	8.2617	–	1.0000	13.7886	–
Control variables		Yes			Yes			Yes			Yes		

Table 9
Regression results of policy.

Variables	Value chain production			Pure GVC production			Pure NVC production			NGVC production		
Explained variable: $posr_{l,pst}$	PIP	Post Mean	Post SD	PIP	Post Mean	Post SD	PIP	Post Mean	Post SD	PIP	Post Mean	Post SD
$\dot{TFP}_{pst}$	0.0830	-0.0023	0.0134	0.9997	-0.1776	0.0371	0.0178	-0.0002	0.0048	0.0240	-0.0006	0.0068
1(t > 2008)	0.4043	0.1197	0.1721	0.7873	-0.1629	0.0928	0.0425	0.0063	0.0434	0.0200	0.0006	0.0125
subsidy income	0.4839	-0.0457	0.0547	0.0575	0.0017	0.0117	0.0324	-0.0014	0.0098	0.0455	-0.0023	0.0132
$TFP_{pst}\times 1(t > 2008)\times$subsidy income	0.4639	-0.1436	0.1905	0.2467	-0.0429	0.0849	0.0340	-0.0053	0.0415	0.0212	-0.0008	0.0130
Constant	1.0000	8.6633	–	1.0000	7.8103	–	1.0000	7.7221	–	1.0000	12.7112	–
Control variables	Yes			Yes			Yes			Yes		

and pure NVC production of regional sectors to move to a relatively upstream position. The impact of technological progress on the position of pure GVC production was completely the opposite. but the positive impact of technological progress on the position of the NGVC production was not obvious.

In conclusion, the impact of technological progress on the position of the value chain before the crisis is not obvious. After the crisis, technological advancement prompted pure GVC production to move to a relatively downstream position, and pure NVC production to move to a relatively upstream position. Finally, technological advancement exerted a small influence on the overall value chain position to move to a relatively upstream position.

5.3.4. Discussion of policy

During the sample period, Chinese government proposed a $4 trillion stimulus package in November 2008, making massive investments to leverage the economy. To estimate the impact of this policy, this paper adds a temporal dummy variable "1" (t > 2008) to the benchmark regression model, which was 0 in 2008 and before, and 1 after 2008. At the same time, this paper has added the interaction of technological progress, the temporal dummy variables of the global economic crisis, and subsidy income. The regression results are shown in Table 9.

The regression results show that after the crisis, the relative position of the value chain production has a tendency to move to the relative upstream, while the pure GVC production is the opposite, and the trend of moving to the relative downstream is basically consistent with the results of Table 8. $\dot{TFP}_{pst} \times 1(t > 2008) \times subsidyincome$ has a significant negative impact on value chain production, as opposed to the influence of the temporal dummy variables of the global economic crisis. This shows that government financial support and technological progress after the global economic crisis have weakened the positive impact of the global economic crisis on the production in the value chain. However, for a pure GVC production, $\dot{TFP}_{pst} \times 1(t > 2008) \times subsidyincome$ has a significant negative impact, which is the same as the influence of the temporal dummy variable of the global economic crisis. This shows that government financial support and technological progress after the global economic crisis have amplified the negative impact of the global economic crisis on the position of a pure GVC production.

6. Conclusion

This paper proposes an extended framework for measuring regional production positions based on the IRICIOT, and constructs a unified measurement system of NVC and GVC for dual value chain. On the basis of theoretical analysis, the empirical evidence on the impact of Chinese technological progress on the position of the value chain (from the multiple paths of technological progress and value chain production) was assessed. The most important findings are discussed below.

The NGVC production length is much longer than that of pure value chain production in China. China is relatively downstream on the whole, but NGVC production is relatively upstream. Before the crisis, the central and western regions were relatively upstream in NGVC production and pure NVC production. After the crisis, the NGVC production in eastern coastal regions shifted to a relatively downstream position. The pure NVC production in central and western regions, continued to move to a relatively upstream position. From a sectoral perspective, most of manufacturing sectors were relatively downstream in terms of production, and manufacturing linkage, while the primary product sector and some low-tech manufacturing sectors are relatively upstream. After the crisis, the average relative position of the manufacturing sector in most regions gradually moved relatively downstream, and was locked in the middle and low-end production process. However, in NGVC production this is not the case as nearly half of the region breaking through this predicament. The government financial support and technological progress after the global economic crisis have weakened the positive impact of the global economic crisis on the production in the value chain, but amplified the negative impact of the global economic crisis on the pure GVC production.

The heterogeneous impact of technological progress on the position of the value chain is manifested in that technological progress will promote the shift of the total value chain production in the eastern region to a relatively upstream position after the crisis (mainly through pure NVC production). At the same time, technological progress will promote the central region and the high-tech manufacturing sector's total value chain production to move to a relatively downstream position. The role of the central region is the production across all value chains, and the role of the high-tech manufacturing sector is the production by pure NVC.

The Chinese eastern region can make full use of its own first-mover advantage, and concentrate on technological progress in the relatively upstream R&D stage of the production chain. For the central region, full emphasis should be placed on its inherent potential, undertaking the downstream production stage of GVC production in the eastern region. For the western region, full emphasis should be placed on its own resource endowment advantages, actively laying out the production in NVC.

Due to the oversupply of low and middle-end products, insufficient supply of mid and high-end products. Although the global flow of products can promote the allocation of resources in the domestic and international markets, such as natural gas trade (Chen et al., 2019), the high-tech manufacturing sector should avoid blindly pursuing the embedding of the GVC, and considered in the domestic market. For other sectors, it should actively seek deeper value chain embedding.

Based on the above empirical analysis, it finds that the relative position of technological progress in the value chain is concentrated in a pure GVC production, and more directed to the downstream sector. At the same time, heterogeneity analysis shows that the negative impact of technological progress on the upstream of a pure GVC mainly comes from the central and western regions, other sectors (excluding high-tech manufacturing sectors in all sectors), and following the global economic crisis. The relative position of technological progress in the value chain is concentrated in the GVC production, and more points to the downstream sector. The main explanation of this finding is: when participating in the production in a pure global value chain, different regional departments have gradually formed their own production characteristics, especially at the regional level, the eastern region due to geographical and economic advantages, its role as a foreign trade bridge has deepened, and when participating in the pure GVC production, it has given priority to undertaking intermediate product inputs from abroad. The central and western regions participate in a pure GVC production after the eastern region. With the development of the national production system, the technological progress of each region will continue to strengthen its own production characteristics, prompting the eastern region to participate in a relatively more upstream position in a pure GVC, while the central and western regions to participate in a relatively more downstream position in a pure GVC, and finally in the analysis at the national level, the characteristics of the relative position of technological progress in the value chain are concentrated in the GVC production and more pointed to the downstream sector.

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Data Availability

I have shared the data/code in a Data in Brief zip file.

Appendix A

Forward decomposition verification

From a regional perspective, when calculating the average production length, it can also be measured from the perspective of intra-regional production. For example, the production within the region and the final goods trade outside the region can be considered. Since all the production processes are completed within the region, production will not be carried out after inflows from other regions and imports from other countries (or regions). Therefore, when calculating the average production length corresponding to production within the region and the final goods trade outside the region, it is weighted average of each production stage corresponds to the inverse of the Leontief matrix in the region L^R. Then, from the perspective of intra-regional production, the total output caused by the regional value added brought by production in the value chain can be expressed as $\widehat{V}^R L^R L^R B_1 Y + \widehat{V}^R L^R L^R A^{RC} B_2 Y$; additionally, the total output (wvr_{intra}) caused by the regional value added onto production in the value chain, production within the region, and the final goods trade outside the region can be expressed as

$$wvr_{intra} = \widehat{V}^R L^R L^R \delta^R Y + \widehat{V}^R L^R L^R A^R B_1 Y + \widehat{V}^R L^R L^R A^{RC} B_2 Y = \widehat{V}^R L^R B_1 Y \tag{A1}$$

where$(L^R\delta^R + L^R A^R B_1 + L^R A^{RC} B_2)Y = X^R = B_1 Y$, so $B_1 = L^R\delta^R + L^R A^R B_1 + L^R A^{RC} B_2$, $L^R\delta^R B = L^R * [I_{s*s} \quad 0_{s*C}] * \begin{bmatrix} B_1 \\ B_2 \end{bmatrix} = [L^R \quad 0_{s*C}] * \begin{bmatrix} B_1 \\ B_2 \end{bmatrix} = L^R B_1$.

After regional outflow and export of intermediate products, other countries (or regions) can still produce further. Therefore, from the perspective of production outside the region, the regional value added mainly comes from production in the value chain, and the total output (wvr_{inter}) caused by the corresponding regional value added can be expressed as

$$wvr_{inter} = \widehat{V}^R L^R A^R B_1 BY + \widehat{V}^R L^R A^{RC} B_2 BY = \widehat{V}^R (B_1 - L^R \delta^R) BY = \widehat{V}^R (B_1 B - L^R B_1) Y \tag{A2}$$

Then, based on the forward industrial linkage, the total output (wvr) caused by the regional value added can be expressed as the sum of the total output caused by the regional value added from the perspective of production within and outside the region. Namely,

$$wvr = wvr_{intra} + wvr_{inter} = \widehat{V}^R L^R B_1 Y + \widehat{V}^R (B_1 - L^R \delta^R) BY = \widehat{V}^R B_1 BY \tag{A3}$$

Eq. (A3) shows that from the perspective of production within and outside the region, the sum of the total output caused by the regional value added brought about by different segments of production is consistent with the overall level of measurement results. The accuracy of the decomposition framework based on forward industrial linkage is verified.

Appendix B

Backward decomposition verification

Similarly, the total input caused by the final use of the region also includes the perspective of production within the region and the perspective of production outside the region. Among them, the final use corresponding to the intra-regional production and the final goods trade outside the region only involves the total intra-regional production, therefore, the total input caused by this part of the

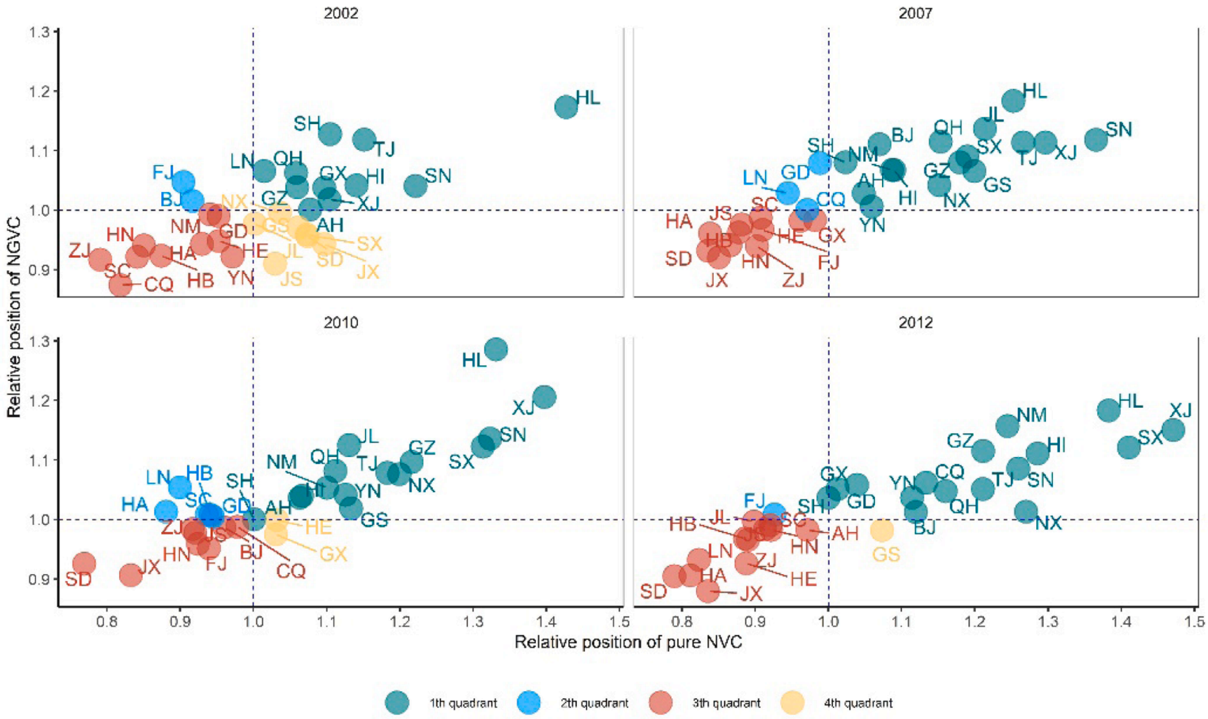

Fig. C1. The relative position of pure NVC production and NGVC production in China's regions. *Notes*: The value uses 1 as its threshold. The larger the value, when it exceeds 1, the closer it is to the relative upstream position of production; the smaller the value, when it is less than 1, the closer it is to the relative downstream position of production.

final use is the part from the perspective of the intra-regional production. For production in the value chain, from the perspective of the production within a region (country), L^R and L^Crespectively reflect the process of production within the region and within a country. To clearly reflect the production linkage contained in it, L^R can be expressed as $I + A^D + A^{D2} + \ldots$, L^C can also be expressed as $I + A^{CD} + A^{CD2} + \ldots$. After weighing the number of production stages, the total input caused by yr_i is $V^R L^R L^R A^R B_1 \widehat{Y}\mu + V^R L^R L^R A^{RC} B_2 \widehat{Y}\mu + V^C L^C L^C A^{CF} B_2 \widehat{Y}\mu + V^C L^C L^C A^{CR} B_1 \widehat{Y}\mu$. Then, from the perspective of the intra-regional production, the total input caused by the final use can be expressed as

$$\begin{aligned} wyr_{intra} &= V^R L^R L^R \delta^R \widehat{Y}\mu + V^R L^R L^R A^R B_1 \widehat{Y}\mu + V^R L^R L^R A^{RC} B_2 \widehat{Y}\mu + V^C L^C L^C A^{CF} B_2 \widehat{Y}\mu + V^C L^C L^C A^{CR} B_1 \widehat{Y}\mu \\ &= V^R L^R B_1 \widehat{Y}\mu + V^C L^C B_2 \widehat{Y}\mu \end{aligned} \quad \text{(B1)}$$

On the other hand, the part that involves the production outside the region is the production of the value chain. Therefore, from the perspective of production outside the region, the total input caused by the final use corresponding to the production of the value chain is expressed as

$$\begin{aligned} wyr_{inter} &= V^R L^R A^R B_1 B \widehat{Y}\mu + V^R L^R A^{RC} B_2 B \widehat{Y}\mu + V^C L^C A^{CF} B_2 B \widehat{Y}\mu + V^C L^C A^{CR} B_1 B \widehat{Y}\mu \\ &= V^R \left(B_1 - L^R \delta^R\right) B \widehat{Y}\mu + V^C \left(B_2 - L^C \delta^C\right) B \widehat{Y}\mu \\ &= V^R \left(B_1 B - L^R B_1\right) \widehat{Y}\mu + V^C \left(B_2 B - L^C B_2\right) \widehat{Y}\mu \end{aligned} \quad \text{(B2)}$$

$L^C \delta^C B = L^C * \left[0_{C*s} \quad I_{C*C}\right] * \begin{bmatrix} B_1 \\ B_2 \end{bmatrix} = L^C B_2$. According to the total output relationship of other countries (or regions), where $L^C \delta^C B = L^C * \left[0_{C*s} \quad I_{C*C}\right] * \begin{bmatrix} B_1 \\ B_2 \end{bmatrix} = L^C B_2$ $X^C = B_2 Y = A^{CR} X + Y^{CR} + A^{CD} X + Y^{CD} + A^{CF} X + Y^{CF} (L^C \delta^C + L^C A^{CF} B_2 + L^C A^{CR} B_1) Y$, there is $L^C \delta^C + L^C A^{CF} B_2 + L^C A^{CR} B_1 = B_2$. Then, considering the production within the region and production outside the region, the total input (*wyr*) resulting from the final use is expressed as

$$\begin{aligned} wyr &= wyr_{intra} + wyr_{inter} \\ &= V^R L^R B_1 \widehat{Y}\mu + V^C L^C B_2 \widehat{Y}\mu + V^R \left(B_1 B - L^R B_1\right) \widehat{Y}\mu + V^C \left(B_2 B - L^C B_2\right) \widehat{Y}\mu = VBB\widehat{Y}\mu \end{aligned} \quad \text{(B3)}$$

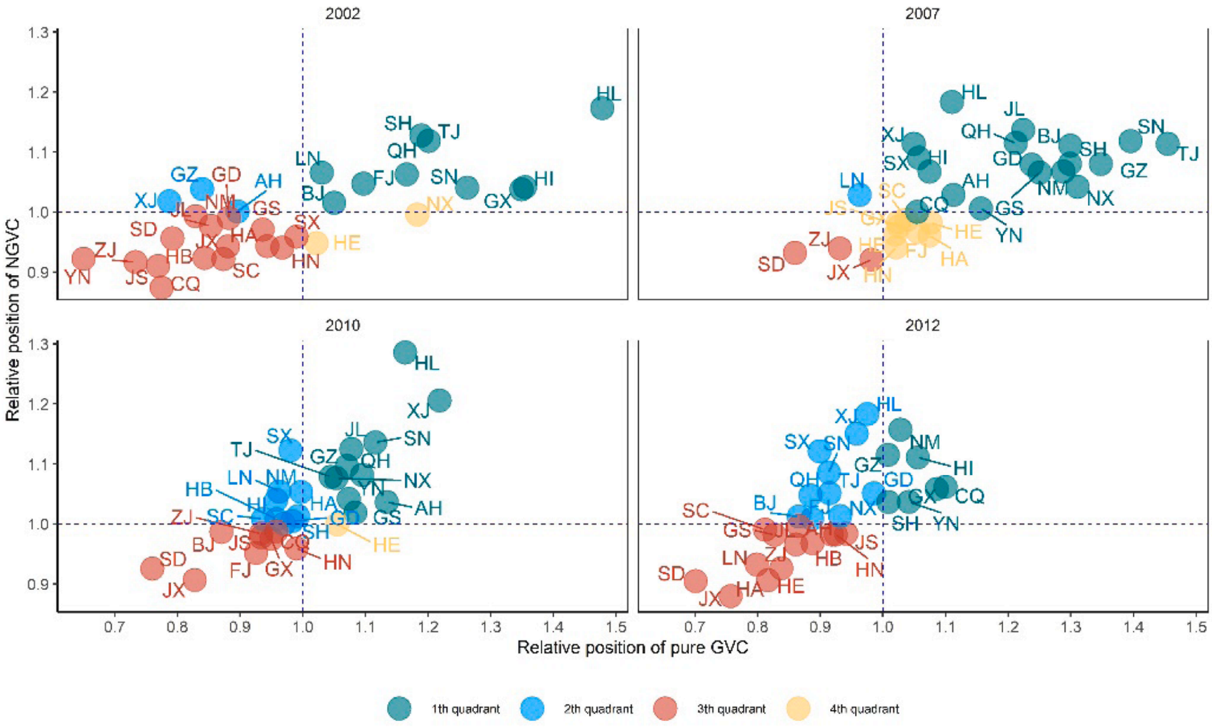

Fig. D1. The relative position of pure GVC production and NGVC production across China's regions. *Notes*: The value uses 1 as its threshold. The larger the value, when it exceeds 1, the closer it is to the relative upstream position of production; the smaller the value, when it is less than 1, the closer it is to the relative downstream position of production.

Appendix C

See appendix Fig. C1.

The relative position of pure NVC production and NGVC production in China

As shown in Fig. C1, in 2002 the central and western regions, such as Heilongjiang, Shaanxi, Guangxi, Guizhou, Xinjiang, and Anhui, were relatively upstream when participating in both pure NVC production and NGVC production. Zhejiang, Chongqing, Guangdong, Sichuan, Hubei, Hunan, and other regions are in the third quadrant, and have relatively downstream production in the two value chains. As time progressed, each region gradually gathered in the first and third quadrants. By 2012, the central and western regions, such as Xinjiang, Shanxi, Heilongjiang, Inner Mongolia, Guizhou, and Shaanxi, were mainly concentrated in the first quadrant and had relatively upstream production in the two value chains.

Appendix D

See appendix Fig. D1.

The relative position of pure GVC production and NGVC production in China

The horizontal axis of Fig. D1 represents the relative position of pure GVC production, and the vertical axis represents the relative position of NGVC production. It can be seen from Figure IV.1 that in 2002, 30 regions in China were roughly divided into two parts by the critical line. Shanghai, Tianjin, Heilongjiang, Beijing, Liaoning, and other regions were in the first quadrant. In pure GVC production and NGVC production, these are relatively upstream. Most of the other regions are concentrated in the third quadrant and are relatively downstream in both value chains, as well as in the production of the two value chains. In 2007, the relative position of some regions participating in pure GVC production improved, while regional polarization weakened. In 2010, each region was mainly concentrated at the intersection of the relative positional thresholds of the production in the two value chains. Only Heilongjiang and Xinjiang remained relatively upstream in the production for both value chains, while Shandong and Jiangxi remained relatively downstream. By 2012, each region was distributed in the first, second, and third quadrants. Chongqing, Guangxi, Inner Mongolia, Yunnan, Hainan, and other regions were relatively upstream in terms of pure GVC production, while Shandong, Jiangxi, Liaoning, Henan, and Sichuan were relatively downstream.

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