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Low-End Lock-In of Chinese Equipment Manufacturing Industry and the Global Value Chain

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Abstract: This paper focuses on the low-end lock-in problem faced by China's equipment manufacturing industry, which is heavily involved in the global value chain (GVC). Specifically, we use the production chain length system and total trade accounting framework to measure some physical and economic location indicators. The physical location measures the forward production length, backward production length, and the location index, whereas the economic location measures various types of value-added in industry exports. The results show that China's equipment manufacturing industry has deepened its physical and economic low-end lock-in with the gradual deepening of China's equipment manufacturing industry's participation in GVC. From a segmented perspective, the manufacture of fabricated metal products (except machinery and equipment) and electrical equipment has the deepest degree of low-end lock-in physical location; the manufacture of computer, electronic, and optical products has the deepest degree of economic low-end lock-in. Therefore, China should accelerate its breakthroughs in the low-end locking dilemma and climb the GVC by adopting various measures such as accelerating the implementation of the intelligent manufacturing strategy, developing service-oriented equipment manufacturing industries, cultivating the domestic market, realizing low-carbon manufacturing, and improving enterprises' independent innovation capabilities.

Keywords: equipment manufacturing industry; global value chains; low-end lock-in; length of global value chains; value-added trade

1. Introduction

With the rapid development of economic globalization, innovation and progress in the fields of information and communication technology, logistics, and transportation services, the international division of labor have gradually surpassed the traditional national and industrial levels, gradually refining from product link to production link. The division of labor model, as the main feature of the global value chain (GVC), is taking a dominant position. Globally, more than two-thirds of world trade occurs through the GVC [1]. The GVC has new features such as multi-polarization, refined division of labor, specialization, and the increasingly important status of services [2]. As a result, international trade has shifted from the original inter- and intra-industry trade dominated by final products to intra-product trade dominated by parts and intermediate products [3]. This change has formed modular production links distributed across countries and regions around the world, forming a global production network and providing the majority of developing countries with the opportunity to participate extensively in and benefit from the GVC division of labor [4]. Antras et al. showed that the formation of GVC network is conducive to developing countries to take advantage of their

comparative advantages to participate in international production division and international market, and to have the opportunity to improve domestic productivity [5]. Developing countries continue to increase their economic growth by continuing reform of their participation in GVCs. China took this opportunity to contribute to its economic development by relying on the export-oriented development strategy integrated into the global production network [6]. Today, China is considered to be a key factor in shaping the global economy, playing an increasingly important role in the GVC [7]. In this context, China's equipment manufacturing industry has actively integrated into the GVC. With abundant and cheap labor, China has engaged in a large number of processing and assembly activities in the GVC division of labor system. The scale of exports has rapidly expanded, forming a GVC division of labor participation model of "maximizing imports and exports and putting both ends outside" [8]. Its industrial value-added and total trade have been far ahead of other developing countries, and even ahead of some developed countries. China has become a veritable manufacturing exporter, but a large exporter is not equal to a strong exporter [9]. The most intuitive manifestation is that a large number of Chinese processed products appear in the international market, labeled as "the world's processing plant", and participate in the low value-added link of the GVC in the international division of labor, with investments in medium- and low-skilled rather than high-skilled labor [10]. More studies are showing that developed countries, as the leaders and drivers of the GVC division of labor, rely on their advanced technology, strong market control, and superior independent innovation capabilities to occupy the high-end links of GVCs. China, in the GVC, is faced with the serious issues of the low-end locking [11]. China's low-end-embedded participation model makes China's equipment manufacturing industry face the risk of being locked in low-value-added links and being marginalized because climbing to high-value-added links is difficult [12]. Especially in recent years, China's labor costs have gradually risen, and its labor advantages have gradually been lost. The status as the world's factory is being threatened and challenged by other developing countries. China's equipment manufacturing industry is experiencing adverse effects of external environmental changes, such as shrinking international market demand and fierce low-end competition in the GVC [13]. Simultaneously, developed countries started a global upsurge in competing for Industry 4.0. In 2012, Germany released the Industry 4.0 plan, and the United States officially launched re-industrialization. A new round of industrial competition in the world started in the high-end manufacturing industry. The Chinese government introduced a series of strategic measures to promote the development of the equipment manufacturing industry. Made in China 2025 provides a clear goal and focus on the development of China's equipment manufacturing industry within 10 years. Guiding opinions on promoting international cooperation in production capacity and equipment manufacturing stated that the core of production capacity cooperation should be the equipment manufacturing industry. Therefore, the characteristics of China's equipment manufacturing industry in the GVC should be studied, as well as its changing trends to explore effective measures to break through the low-end lock-in [14].

2. Literature Review

Many scholars have studied the causes and drawbacks of low-end lock-in of GVCs. Outdated technology, insufficient independent innovation capability, lack of human capital, insufficient domestic demand, and institutional barriers are the main reasons for the low-end lock-in of the GVC of China's equipment manufacturing industry [15]. Schmitz and Knorrnga [16] reported that the Original Equipment Manufacturer (OEM) production method makes it difficult for enterprises to form their own R&D design systems, independent brands, production systems, and market channels. The lack of their own capabilities creates challenges to participation in many high value-added strategic activities, such as design, marketing, and branding, which has prevented companies from upgrading the value chain over time and trapped them in the "low-end" of the value chain. Grunsven and Smakman [17] stated that the reason for the low-end lock-in of Singapore's apparel industry lies in the following three aspects: capability gap, sedimentation cost, and transformation cost. Timmer et al. [18] decomposed

the added value implied in the final product and found that capital and high-tech labor force had an increasingly important impact on the GVC status. The excessive reliance on capital and low-skilled labor force lagged China behind developed countries and placed the country at the low-end of the GVC. Tschang and Goldstein [19] and Lvarsson and Alvstam [20] pointed out that developing countries have shortcomings in strategic factors such as advanced technology and human capital, and their ability to digest and absorb technology is poor. Ren et al. [21] emphasized that the internal constraints of insufficient domestic demand and institutional barriers are the most important domestic reasons causing Chinese local companies to be locked in the low-end of the GVC, which leads to rational OEMs replacing the outward-looking chain mode with the inward-looking chain mode.

At the micro-level, the low-end embedded model of the value chain makes it easy for Chinese companies to form technological dependence on high-end location companies. Buckley [22] stated that once this technology acquisition path is formed, low-end embedded companies become accustomed to imitating and rejecting technological innovation, which is not conducive to the cultivation and improvement of technological innovation capabilities. This further aggravates the low-end lock-in effect, forming a vicious circle, falling into a low growth situation. The return on economic activities will continue to decline [23]. Long-term low-end locking forces enterprises onto a path of low income and low cost, and causes negative externalities such as resource waste and environmental degradation [24]. At the macro-level, low-end lock-in restricts industrial upgrading creates dependence risk, value poverty risk, strategic marginalization risk, competition deterioration risk, and industry hollowing risk for industrial clusters [25]. It easily leads to the trend of “poverty growth” and “dependent economy” [26], resulting in an imbalance in the export trade structure [27].

In terms of methods to measure whether a low-end lock-in of the GVC exists in a certain industry in a country, the research can be divided into two categories: measuring the position of an industry in the GVC division of labor, which is the physical location, and measuring the profitability of an industry in the division of GVCs, which is the economic location [28]. In the measurement of physical location, the most representative frame is the upstream degree index proposed by Antras et al. [5] and the downstream degree index proposed by Antras and Chor [29], which respectively represent the number of production stages required to produce a certain industry’s final product and the number of production stages in an intermediate input in the industry before forming the final product. The larger the upstream degree index, the higher the position of the industry in the GVC [30]. The larger the downstream degree index, the more the industry tends to embed in low-end GVCs [31]. Lu [32] measured the upstream degree index of China’s manufacturing industry and found that the degree of its participation in GVCs has deepened but it has been locked in the low end of the GVC division of labor. Wang et al. [33] built a production chain length system based on Fally et al. that can decompose the total production length in the world economy into different parts and accurately measure the length of the GVC based on the value-added and the breakdown of end-product production activities.

In the measurement of economic location, the Vertical Specialization (VS) index constructed by Hummels et al. [34], laid the foundation for the measurement of economic location, and the “value-added trade” proposed by the Organization for Economic Cooperation and Development (OECD) and the World Trade Organization (WTO) [35] had loosened the assumption of vertical specialization indicators that “all imported intermediate products are composed entirely of foreign value-added”, so it is a closer estimation to the actual division of labor in the GVC. Johnson and Noguera [36] proposed the concept of value-added export (VAX) on this basis and used the proportion of value-added export over total exports (VAX ratio) as the measurement index to measure the economic location of GVC division of labor. Koopman et al. [37] proposed a value-added trade accounting framework first that decomposes a country’s total exports into domestic value-added absorbed by foreign countries (that is, VAX), returned domestic value-added, foreign value-added, and pure double-counting part. Wang et al. [38] pointed out that Koopman et al. only decomposed a country’s total exports and cannot be extended to the trade flow decomposition of sectors, bilateral, and bilateral sector-level. Therefore, according to the difference in source place, absorption place, and absorption

channels, in this study, we divided the total exports of a country into 16 parts and, thus, a new total trade accounting framework was established.

Based on the analysis of the literature, the possible marginal contribution of this paper lies in deducing the physical location based on the production chain length index system and calculating the economic location according to the total trade accounting framework. From the two aspects of physical location and economic location, we comprehensively analyzed the low-end locking of China's equipment manufacturing industry in the GVC, which fills the gap in the existing research, enriches the indicators for measuring the division of GVCs, and promotes the refinement and deepening of GVC theories. The findings also provide practical advice to break through the low-end lock-in dilemma of China's equipment manufacturing industry with the aim to promote it to climb up the value chain.

3. Indicator Construction and Data Sources

We used the production chain accounting methods to estimate the global production value chain length of China's equipment manufacturing industry's six segmentation industries, which includes the forward length of the value chain (PLv_GVC) and the backward length of the value chain (PLy_GVC), and we further decomposed PLv_GVC into three parts based on the weight of domestic value-added, it includes (1) directly absorbed by the importing country: PLv_GVC_R, (2) absorbed by the source country: PLv_GVC_D, (3) indirectly absorbed by other Countries: PLv_GVC_F for further analysis (also similar to PLy_GVC). On this basis, the country's position index was calculated by the ratio of the production length of the GVC forward and backward to express its physical location in the industrial GVC. Wang et al. built the total trade accounting framework, for the 16 parts of a country's total export calculating the export industry domestic value-added in the proportion of total exports final goods and services exports (DVA_FIN) and immediate exports absorbed by the direct importer (DVA_INT), to measure the export capacity of the value-added of China's equipment manufacturing industry in the GVC, to show its economic location on the GVC in the industry. The details of the method are as follows.

3.1. The Production Chain Length System

The production chain length system improves and optimizes the upstream degree index defined by Chor et al. and the downstream degree index defined by Antras and Chor. This production chain length system decomposed the value chain based on the value-added and final product and proposed a production chain length system based on forward and backward linkages between industries. The total production length is decomposed into pure domestic parts, traditional trade-related parts, and GVC trade-related parts. The GVC trade-related part can be further broken down into three categories: the part directly absorbed by the importing country, the part absorbed by the source country, and the part indirectly absorbed by other countries, based on the weightage of the domestic value-added. Simultaneously, the accounting method of production chain length can be divided into two parts, domestic and international, by simple addition. The specific structure is shown in Figure 1.

We considered the Inter-Country Input–Output (ICIO) model of N industries in M countries, whose structure is shown in Table 1.

Table 1. Input–output table between general countries.

Outputs Inputs	Intermediate Use				Final Demand				Total Output	
	1	2	...	M	1	2	...	M		
Intermediate input	1	Z^{11}	Z^{12}	...	Z^{1m}	Y^{11}	Y^{12}	...	Y^{1g}	X^1
	2	Z^{21}	Z^{22}	...	Z^{2m}	Y^{21}	Y^{22}	...	Y^{2g}	X^2
	\vdots	\vdots	\vdots	\ddots	\vdots	\vdots	\vdots	\ddots	\vdots	\vdots
	M	Z^{m1}	Z^{m2}	...	Z^{mm}	Y^{m1}	Y^{m2}	...	Y^{mg}	X^m
Value-added		Va^1	Va^2	...	Va^m					
Total input		$(X^1)^y$	$(X^2)^y$...	$(X^m)^y$					

Z^{sr} is an $N \times N$ matrix of intermediate input flows, which represents intermediate input produced by country s and used by country r . Y^{sr} is an $N \times 1$ vector representing final products produced by country s and consumed by country r . X^s is also an $N \times 1$ vector representing the total output of country s , and Va^s is an $N \times 1$ vector representing the direct value-added of country s . The input coefficient matrix can be defined as $A = Z\hat{X}^{-1}$, where \hat{X} is the diagonal matrix of the output vector X . The value-added coefficient vector can be defined as $V = Va\hat{X}^{-1}$. The total output X can be broken down into intermediate and final products, $AX + Y = X$. By sorting, the classic Leontief [39] equation can be obtained, $X = BY$, where $B = (I - A)^{-1}$ is the Leontief inverse matrix.

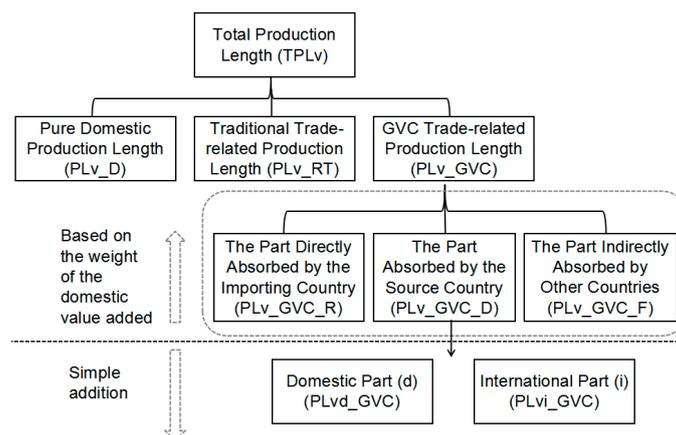


Figure 1. The production chain length system. Note: The picture shows the production chain length system based on the forward association between industries. As for the production chain length system based on the backward association between industries, “v” must be replaced with “y”.

According to the Leontief method for analyzing the quantitative dependence between input and output in a specific economic system, the value-added and final product in the global ICIO model specified in Table 1 are related by the following equation: $Va' = \hat{V}X = \hat{V}BY$. If industry i and industry j are the same, the initial investment (value-added) of industry i can only be directly reflected in the final product of industry j . Therefore, in the first stage of any production process, the value-added of industry i implicit in the final product of industry j can be quantified as $\delta_{ij}v_iy_j$, where δ_{ij} is a dummy variable. If i and j are the same, δ_{ij} is equal to 1, otherwise, it is equal to 0. At this stage, the length of the production chain is 1, and the output in this production chain (induced by the production chain) is $\delta_{ij}v_iy_j$.

In the second stage, the value-added of industry i is directly reflected in the total output, as an intermediate product to produce the final product of industry j can be called $v_i a_{ij} y_j$. This is the value-added (in the first round) of industry i implicit indirectly in the final product of industry j . At this stage, the length of the production chain is 2, and the output produced by the production chain is $2v_i a_{ij} y_j$, and value-added $v_i a_{ij} y_j$, as the output, has been calculated twice: once for industry i and once for industry j .

In the third stage, the indirect value-added of industry i is implicit in the intermediate products of any industry, and these intermediate products are used to produce the final product of industry j . At this stage, the domestic value-added of industry i can be recorded as $v_i \sum_k^n a_{ik} a_{kj} y_j$. This is the second round of the indirect value-added of industry i , which is implicit in the intermediate products used by any industry k and absorbed by the final product of industry j . At this stage, the length of the production chain is 3, and the output induced by the production chain is $3v_i \sum_k^n a_{ik} a_{kj} y_j$. The same value-added produced by industry i was calculated as output three times: once in industry i , once in industry k , and once in industry j . The same was applied for the subsequent stages.

Summarizing the above processes and including the value-added of all rounds directly and indirectly created by industry i in the final product of industry j , we obtain:

$$\delta_{ij}v_i y_j + v_i a_{ij} y_j + v_i \sum_k^n a_{ik} a_{kj} y_j + \dots = v_i b_{ij} y_j \delta_{ij} = \begin{cases} 1, i = j \\ 0, i \neq j \end{cases} \quad (1)$$

Expressed as a matrix, this is:

$$\begin{aligned} \hat{V}\hat{Y} + \hat{V}A\hat{Y} + \hat{V}AA\hat{Y} + \dots &= \hat{V}(I + A + AA + \dots)\hat{Y} = \hat{V}(I - A)^{-1}\hat{Y} \\ &= \hat{V}B\hat{Y} = \begin{bmatrix} v_1 b_{11} y_1 & \dots & v_1 b_{1n} y_n \\ \vdots & \ddots & \vdots \\ v_n b_{n1} y_1 & \dots & v_n b_{nn} y_n \end{bmatrix} \end{aligned} \quad (2)$$

Each element in the matrix represents the value-added of the source sector used directly or indirectly for the production of final products in the destination industry. The elements $v_i b_{ij} y_j$ of the i -th row and the j -th column in the matrix are the total value-added of industry i in the final product of industry j . The rows of the matrix represent the value-added generated by the specific industry that is reflected in the final product of all industries. The columns of the matrix represent the value-added contribution of all source industries in the final product produced by a particular industry.

Using the length of each stage as a weight and summing all production stages, we obtain the total output of a specific production chain (induced) (industry i to industry j) as:

$$\delta_{ij}v_i y_j + 2v_i a_{ij} y_j + 3v_i \sum_k^n a_{ik} a_{kj} y_j + \dots = v_i \sum_k^n b_{ik} b_{kj} y_j \delta_{ij} = \begin{cases} 1, i = j \\ 0, i \neq j \end{cases} \quad (3)$$

Expressed as a matrix, this is:

$$\begin{aligned} \hat{V}\hat{Y} + 2\hat{V}A\hat{Y} + 3\hat{V}AA\hat{Y} + \dots &= \hat{V}(I + 2A + 3AA + \dots)\hat{Y} \\ &= \hat{V}(B + AB + AAB + \dots)\hat{V}BB\hat{Y} \end{aligned} \quad (4)$$

From this, the total average production length of the value-added generated by industry i can be obtained, which is the average production length based on the forward industry association. This can be expressed in a matrix as:

$$PLv = \frac{\hat{V}BB\hat{Y}\mu}{\hat{V}B\hat{Y}\mu} = \frac{\hat{V}BBY}{\hat{V}BY} = \hat{X}^{-1}BX = \hat{X}^{-1}B\hat{X}\mu' = G\mu' \quad (5)$$

where μ is a $1 \times N$ unit vector with all its elements 1 and G is the inverse Gaussian matrix.

According to similar logic, the total production length based on backward industry associations can be expressed as a matrix as:

$$PLy = \frac{\mu\hat{V}BB\hat{Y}}{\mu\hat{V}B\hat{Y}} = \frac{VBB\hat{Y}}{VB\hat{Y}} = \mu B \quad (6)$$

We only studied the GVC production length part of the total production length. According to the above logic to decompose the value chain based on value-added, the domestic value-added contained in the intermediate exports of the source country can be broken down into three parts:

$$\begin{aligned}
 V_GVC^s = & \underbrace{\hat{V}^s L^{ss} \sum_{r \neq s}^G A^{sr} L^{rr} \gamma^{rr}}_{V_GVC_R} + \underbrace{\hat{V}^s L^{ss} \sum_{r \neq s}^G A^{sr} \sum_u^G B^{ru} \gamma^{us}}_{V_GVC_D} \\
 & + \underbrace{\hat{V}^s L^{ss} \sum_{r \neq s}^G A^{sr} \left(\sum_u^G B^{ru} \sum_{t \neq s}^G \gamma^{ut} - L^{rr} \gamma^{rr} \right)}_{V_GVC_F}
 \end{aligned} \quad (7)$$

The domestic value-added (V_GVC_R) of the source country directly absorbed by the importing country r in the bilateral intermediate goods exports, the domestic value-added (V_GVC_D) returned by and absorbed by the country s , and the domestic value-added used by the importing country r for producing final or intermediate production and eventually absorbed by a third country (indirectly absorbed by a direct importing country or re-exported to a third country, V_GVC_F), Among them, $L^{ss} = (I - A^{ss})^{-1}$ represents the inverse Leontief matrix in country s . All these are involved in foreign production activities and recorded as GVC-related domestic value-added production activities. Then, related to GVC trade, the total output of the country s caused by the country's domestic value-added is:

$$\begin{aligned}
 Xvd_GVC^s = & \underbrace{\hat{V}^s L^{ss} L^{ss} \sum_{r \neq s}^G A^{sr} L^{rr} L^{rr}}_{Xvd_GVC_R} + \underbrace{\hat{V}^s L^{ss} L^{ss} \sum_{r \neq s}^G A^{sr} \sum_u^G B^{ru} \gamma^{us}}_{Xvd_GVC_D} \\
 & + \underbrace{\hat{V}^s L^{ss} L^{ss} \sum_{r \neq s}^G A^{sr} \left(\sum_u^G B^{ru} \sum_{t \neq s}^G \gamma^{ut} - L^{rr} \gamma^{rr} \right)}_{Xvd_GVC_F}
 \end{aligned} \quad (8)$$

Therefore, the average domestic production length of GVC exports is the weighted sum of the total output of the three components in Equation (8) and its corresponding domestic value-added ratio:

$$PLvd_GVC^s = \frac{Xvd_GVC^s}{V_GVC^s} = \frac{\sum_k^M V_GVC_k^s * PLvd_GVC_k^s}{V_GVC^s} \quad M = (R, D, F) \quad (9)$$

The average domestic production length of the three parts is recorded as $PLvd_GVC_R^s$, $PLvd_GVC_D^s$, and $PLvd_GVC_F^s$, respectively.

Similarly, the total international (foreign) output produced by the domestic value-added of the countries included in the GVC-related intermediate exports can be expressed as:

$$\begin{aligned}
 Xvi_GVC^s = & \underbrace{\hat{V}^s L^{ss} \sum_{r \neq s}^G A^{sr} L^{rr} L^{rr} \gamma^{rr}}_{Xvi_GVC_R} + \underbrace{\hat{V}^s L^{ss} \sum_{r \neq s}^G A^{sr} \sum_v^G B^{rv} \sum_u^G B^{vu} \gamma^{us}}_{Xvi_GVC_D} \\
 & + \underbrace{\hat{V}^s L^{ss} \sum_{r \neq s}^G A^{sr} \left(\sum_v^G B^{rv} \sum_u^G B^{vu} \sum_{t \neq s}^G \gamma^{ut} - L^{rr} L^{rr} \gamma^{rr} \right)}_{Xvi_GVC_F}
 \end{aligned} \quad (10)$$

The average international production length of GVC exports from country s is the weighted sum of the proportion of the total output of the three components in Equation (10) and its corresponding domestic value-added:

$$PLvi_GVC^s = \frac{Xvi_GVC^s}{V_GVC^s} = \frac{\sum_k^M V_GVC_k^{sr} * PLvi_GVC_k^{sr}}{V_GVC^{sr}} \quad M = (R, D, F) \quad (11)$$

The average international production lengths of the three components are recorded as $PLvi_GVC_R^s$, $PLvi_GVC_D^s$, and $PLvi_GVC_F^s$, respectively.

Adding Equations (9) and (11), the total average production length of country s implied by bilateral intermediate product exports is as follows:

$$\begin{aligned}
 PLv_GVC^s &= PLvd_GVC^s + PLvi_GVC^s \\
 &= \frac{Xvd_GVC^s}{V_GVC^s} + \frac{Xvi_GVC^s}{V_GVC^s} = \frac{Xv_GVC^s}{V_GVC^s}
 \end{aligned}
 \tag{12}$$

Decomposing the value chain based on the final product and service according to the above logic, we can obtain the length of GVC production based on backward industry associations as:

$$\begin{aligned}
 PLyd_GVC^s &= \frac{Xyd_GVC^s}{Y_GVC^s} = \frac{\sum_k^M Y_GVC_k^s * PLyd_GVC_k^s}{Y_GVC^s} \\
 M &= (R, D, F)
 \end{aligned}
 \tag{13}$$

$$\begin{aligned}
 PLyi_GVC^s &= \frac{Xyi_GVC^s}{Y_GVC^s} = \frac{\sum_k^M V_GVC_k^{sr} * PLyi_GVC_k^{sr}}{Y_GVC^{sr}} \\
 M &= (R, D, F)
 \end{aligned}
 \tag{14}$$

$$\begin{aligned}
 PLy_GVC^s &= PLyd_GVC^s + PLyi_GVC^s \\
 &= \frac{Xyd_GVC^s}{Y_GVC^s} + \frac{Xyi_GVC^s}{Y_GVC^s} = \frac{Xy_GVC^s}{Y_GVC^s}
 \end{aligned}
 \tag{15}$$

Summarizing the above parts, we can obtain the GVC production length system as shown in Figure 2. Among them, simple cross-border production (PL_GVC_shallow) indicates that the domestic value-added only cross the border once, representing the shallow participation in the GVC. Complex cross-border production (PL_GVC_deep) indicates that the domestic value-added has experienced multiple border crossings, representing deep integration in the GVC [40].

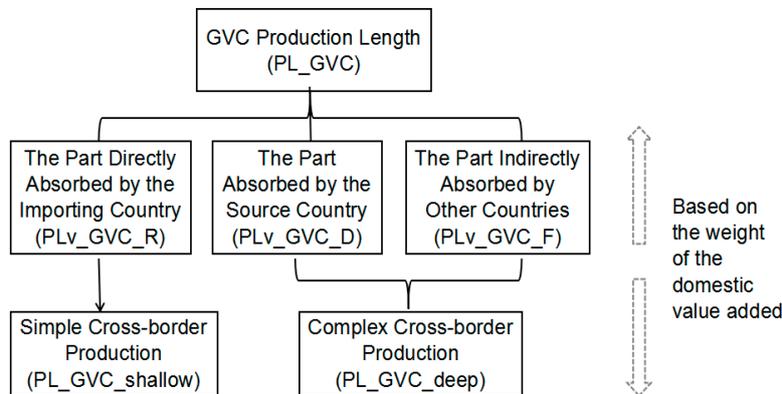


Figure 2. Global value chain (GVC) production length system.

As a special production node in the global production network, the longer the production length of industry i based on the forward linkage between industries, the more upstream it is in the production chain. If the production length of industry i based on the backward linkage between industries is longer, the more downstream it is in the production chain. Therefore, the position of industry i in country s in GVC can be defined as the ratio of the two production lengths:

$$GVC_Pos^s = \frac{PLv_GVC^s}{[PLy_GVC^s]'}
 \tag{16}$$

The larger the index, the more a particular country/industry is upstream of the GVC, the smaller the index, the more downstream it is.

3.2. The Total Trade Accounting Framework

According to the input–output table given in Table 1, suppose there are three economies: s , r and t , and N industries, which can be obtained according to the classic Leontief equation $X = BY$:

$$\begin{bmatrix} X^s \\ X^r \\ X^t \end{bmatrix} = \begin{bmatrix} B^{ss} & B^{sr} & B^{st} \\ B^{rs} & B^{rr} & B^{rt} \\ B^{ts} & B^{tr} & B^{tt} \end{bmatrix} \begin{bmatrix} Y^{ss} + Y^{sr} + Y^{st} \\ Y^{rs} + Y^{rr} + Y^{rt} \\ Y^{ts} + Y^{tr} + Y^{tt} \end{bmatrix} \quad (17)$$

Expanding the right side of Equation (17), decompose the total output X^r of country r into the output driven by different final products:

$$X^r = B^{rs}Y^{ss} + B^{rs}Y^{sr} + B^{rs}Y^{st} + B^{rr}Y^{rs} + B^{rr}Y^{rr} + B^{rr}Y^{rt} + B^{rt}Y^{ts} + B^{rt}Y^{tr} + B^{rt}Y^{tt} \quad (18)$$

Therefore, according to the final absorption place and absorption channel, the intermediate export from country s to country r can be broken down into the following 9 parts:

$$\begin{aligned} Z^{sr} = A^{sr}X^r = & A^{sr}B^{rs}Y^{ss} + A^{sr}B^{rs}Y^{sr} + A^{sr}B^{rs}Y^{st} + A^{sr}B^{rr}Y^{rs} + A^{sr}B^{rr}Y^{rr} \\ & + A^{sr}B^{rr}Y^{rt} + A^{sr}B^{rt}Y^{ts} + A^{sr}B^{rt}Y^{tr} + A^{sr}B^{rt}Y^{tt} \end{aligned} \quad (19)$$

According to the foregoing, the value-added coefficient of country s is $V^s = Va^s(X^s)^{-1}$, V^r and V^t are similar, and the full value-added coefficient is:

$$\begin{aligned} VB &= \begin{bmatrix} V^s & V^r & V^t \end{bmatrix} \begin{bmatrix} B^{ss} & B^{sr} & B^{st} \\ B^{rs} & B^{rr} & B^{rt} \\ B^{ts} & B^{tr} & B^{tt} \end{bmatrix} \\ &= \begin{bmatrix} V^sB^{ss} + V^rB^{rs} + V^tB^{ts}, & V^sB^{sr} + V^rB^{rr} + V^tB^{tr}, & V^sB^{st} + V^rB^{rt} + V^tB^{tt} \end{bmatrix} \end{aligned} \quad (20)$$

Each element in the result of the equation is equal to 1, that is, any unit of the final product can be decomposed into the value-added of all countries and all industries. For country s :

$$V^sB^{ss} + V^rB^{rs} + V^tB^{ts} = uu = (1, 1, \dots, 1) \quad (21)$$

Let E^{sr} denote the export from country s to country r , $E^{sr} = A^{sr}X^r + Y^{sr}$. The right side of the equation represents the middle and final exports. The total exports of country s can also be expressed as $E^s + E^{sr} + E^{st} = A^{sr}X^r + A^{st}X^t + Y^{sr} + Y^{st}$. Country r is similar to country t . So, there are:

$$\begin{aligned} \begin{bmatrix} X^s \\ X^r \\ X^t \end{bmatrix} &= \begin{bmatrix} A^{ss} & 0 & 0 \\ 0 & A^{rr} & 0 \\ 0 & 0 & A^{tt} \end{bmatrix} \begin{bmatrix} X^s \\ X^r \\ X^t \end{bmatrix} + \begin{bmatrix} Y^{ss} + E^s \\ Y^{rr} + E^r \\ Y^{tt} + E^t \end{bmatrix} \\ &= \begin{bmatrix} I - A^{ss} & 0 & 0 \\ 0 & I - A^{rr} & 0 \\ 0 & 0 & I - A^{tt} \end{bmatrix}^{-1} \begin{bmatrix} Y^{ss} + E^s \\ Y^{rr} + E^r \\ Y^{tt} + E^t \end{bmatrix} = \begin{bmatrix} L^{ss}Y^{ss} + L^{ss}E^s \\ L^{rr}Y^{rr} + L^{rr}E^r \\ L^{tt}Y^{tt} + L^{tt}E^t \end{bmatrix} \end{aligned} \quad (22)$$

According to Equation (22), the intermediate export from country s to country r can be expressed as:

$$Z^{sr} = A^{sr}X^r = A^{sr}L^{rr}Y^{rr} + A^{sr}L^{rr}E^r \quad (23)$$

Combining Equations (19), (21), and (23), the export of E^{sr} from country s to country r can be broken down into:

$$\begin{aligned}
 E^{sr} &= A^{sr}X^r + Y^{sr} = (V^sB^{ss})'\#Y^{sr} + (V^rB^{rs})'\#Y^{sr} + (V^tB^{ts})'\#Y^{sr} \\
 &+ (V^sB^{ss})'\#(A^{sr}X^r) + (V^rB^{rs})'\#(A^{sr}X^r) + (V^tB^{ts})'\#(A^{sr}X^r) \\
 &= (V^sB^{ss})'\#Y^{sr} + (V^sL^{ss})'\#(A^{sr}B^{rr}Y^{rr}) + (V^sL^{ss})'\#(A^{sr}B^{rt}Y^{tt}) \\
 &+ (V^sL^{ss})'\#(A^{sr}B^{rr}Y^{rt}) + (V^sL^{ss})'\#(A^{sr}B^{rt}Y^{tr}) + (V^sL^{ss})'\#(A^{sr}B^{rr}Y^{rs}) \\
 &+ (V^sL^{ss})'\#(A^{sr}B^{rt}Y^{ts}) + (V^sL^{ss})'\#(A^{sr}B^{rs}Y^{ss}) \\
 &+ (V^sL^{ss})'\#[A^{sr}B^{rs}(Y^{sr} + Y^{st})] + (V^sB^{ss} - V^sL^{ss})'\#(A^{sr}X^r) \\
 &+ (V^rB^{rs})'\#Y^{sr} + (V^rB^{rs})'\#(A^{sr}L^{rr}Y^{rr}) + (V^rB^{rs})'\#(A^{sr}L^{rr}E^r) \\
 &+ (V^tB^{ts})'\#Y^{sr} + (V^tB^{ts})'\#(A^{sr}L^{rr}Y^{rr}) + (V^tB^{ts})'\#(A^{sr}L^{rr}E^r)
 \end{aligned} \tag{24}$$

The 16 related items are combined and all export partners are aggregated. The total export breakdown of a country is shown in Figure 3.

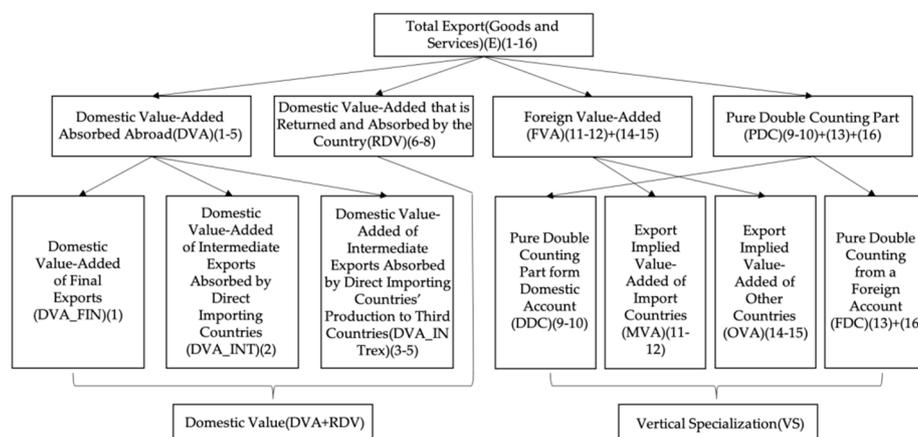


Figure 3. Total trade accounting framework.

3.3. Data Sources

The original data used in this study were obtained from the latest World Input–Output Database (WIOD) (2016), covering continuous time-series data of 44 economies (43 countries and regions and in the rest of the world) and 56 industries from 2000 to 2014 [41]. We selected six sub-sectors of the equipment manufacturing industry: metal product manufacturing (except mechanical equipment) (C25), computer, electronic, and optical equipment manufacturing (C26), power equipment manufacturing (C27), machinery and equipment manufacturing without elsewhere classified (C28), automobile, trailer, and semi-trailer manufacturing (C29), and other transportation equipment manufacturing (C30). The processed data were obtained from the Research Institute for GVC of the University of International Business and Economics [42].

4. Measurement and Analysis of Chinese Equipment Manufacturing Industry's Participation in GVCs

4.1. Physical Location

4.1.1. Length of GVC of China's Equipment Manufacturing

Figure 4 summarizes the length of the GVC for each sub-sector of the equipment manufacturing industry calculated according to the production chain length system.

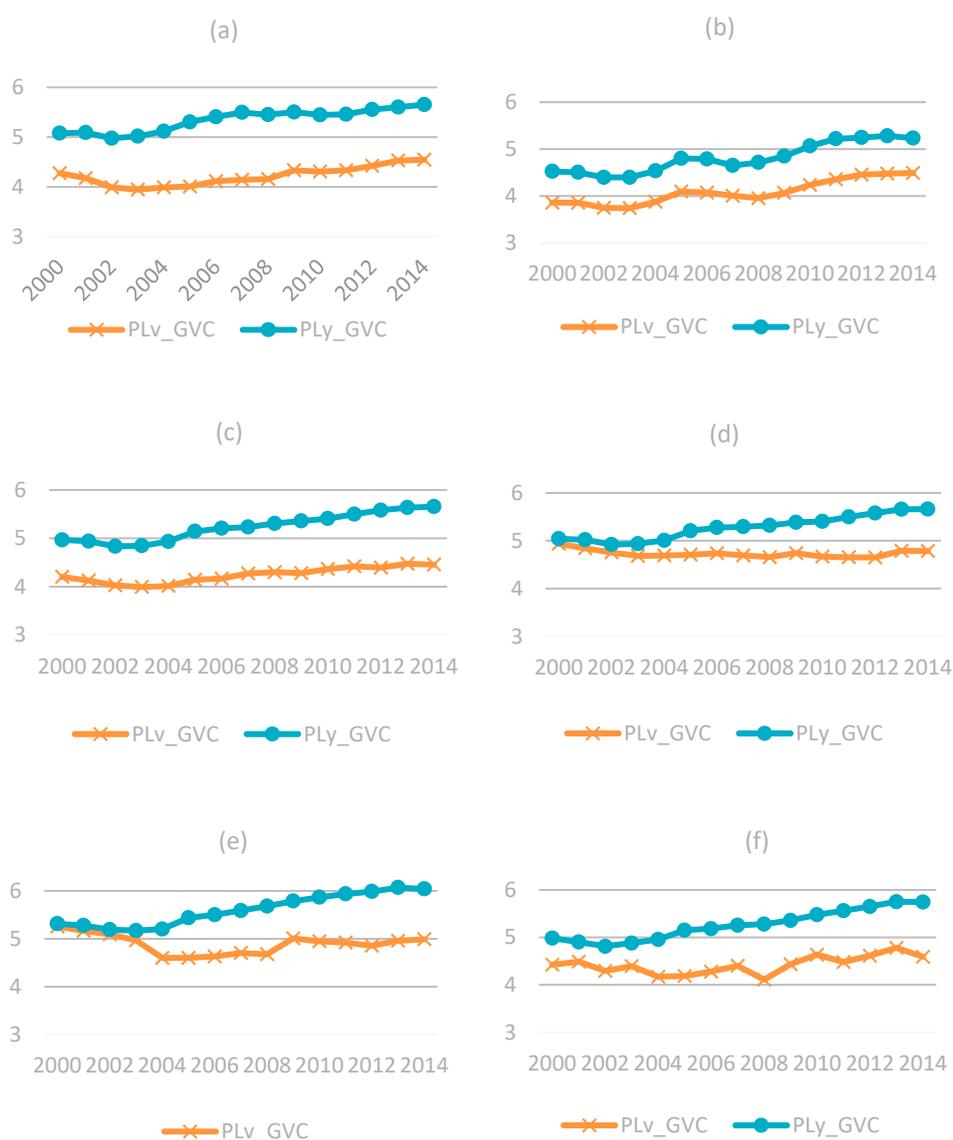


Figure 4. The length of the GVC of each subdivision industry in China's equipment manufacturing industry. (a–f) represent the metal products (except mechanical equipment) manufacturing industry (C25); the computer, electronic and optical equipment manufacturing industry (C26); power equipment manufacturing industry (C27); machinery and equipment not otherwise classified manufacturing industry (C28); the automobile, trailer, and semi-trailer manufacturing industry (C29); other transportation equipment manufacturing industry (C30) respectively. Data source: Calculated based on data from World Input-Output Database (WIOD) and the Research Institute for GVC of the University of International Business and Economics.

First, numerically, the backward length of the value chain of each subdivision industry in China's equipment manufacturing industry is always longer than the forward length, which is consistent with other countries such as the United States, India, and Mexico. However, the backward length of the value chain of China's equipment manufacturing industry is longer than that of other countries (see Appendix A), which indicates that China's equipment manufacturing industry is at the end of the global value chain, and the number of backward production stages is always higher than the forward production stages, which indicates that China's equipment manufacturing industry is at a lower position in the GVC and it has more downstream production stages than upstream ones. From the forward length of the value chain, during 2000–2014, the longest chain was car, trailer, and semi-trailer

manufacturing (C29), with a forward length of 4.99 in 2014. The second was not otherwise classified (C28) machinery and equipment manufacturing, with a forward length of 4.78 in 2014. The domestic value-added produced by these two industries after nearly five production stages that are converted into the final product is absorbed by the ultimate consumer. In 2014, the forward length of the value chain was the shortest, that is, the manufacturing of electric power equipment (C27), had a forward length of 4.46. The domestic value-added had to undergo four production stages before it was finally absorbed. From the backward length of the value chain, from 2000 to 2014, the shortest backward length of the value chain was computer, electronic, and optical equipment manufacturing (C26), with 5.23 in 2014. The longest was still automobile, trailer, and semi-trailer manufacturing (C29), with 6.04 in 2014. This is because the automotive industry has a higher degree of production modularity and more production links, and belongs to an industry with a higher degree of division of the value chain.

Secondly, from the perspective of the changing trend, the backward length of the value chain of each subdivision of China's equipment manufacturing industry was extended, and the extension was about 0.7. For example, the backward length of the value chain of metal products manufacturing (except mechanical equipment) (C25) was 5.08 in 2000 and 5.65 in 2014. The backward length of the value chain of power equipment manufacturing (C27) was 4.96 in 2000 and 5.65 in 2014. The backward length of the value chain of automobile, trailer, and semi-trailer manufacturing industry (C29) was 5.31 in 2000 and 6.04 in 2014, with the difference value of 0.7. The trends of the changes were basically the same, which indicates that the backward participation of GVC of China's equipment manufacturing industry has deepened, and the number of production stages of the transformation from the domestic value-added of other countries into final products consumed by Chinese consumers have increased. The sub-sectors perform differently in the change in the forward length of the value chain. The metal product manufacturing industry (except mechanical equipment) (C25) and the power equipment manufacturing industry (C27) showed a slight decline first and then gradually increased. The wave range was relatively small, which was extended by about 0.3 compared with 2000 in 2014. The changing trend in the forward length of the computer, electronic, and optical equipment manufacturing industry (C26) was consistent with the change in its backward length, showing a gentle "W" shape, which was extended by 0.6 compared with 2000 in 2014. Other transportation equipment manufacturing (C30) fluctuated more frequently, extending by about 0.2. However, the forward length of machinery and equipment manufacturing not elsewhere classified (C28) and automobile, trailer, and semi-trailer manufacturing industry (C29) shortened to varying degrees, but the change in the automobile, trailer, and semi-trailer manufacturing industry (C29) was larger.

After 15 years of development, although China's equipment manufacturing industry has continued to deepen its participation in the GVC and its independent R&D capabilities have also improved to a certain extent, the gaps between the backward and forward lengths of some subdivided industries have widened significantly. The situation of the equipment manufacturing industry in the downstream of the GVC has not remained unchanged. It has become more severe, still trapped in the low-end lock-in dilemma in terms of physical location.

4.1.2. Decomposition of the GVC Length of China's Equipment Manufacturing Industry

According to the production chain length system, the length of the GVC of a specific industry in a country is divided into three parts, PL_GVC_R , PL_GVC_D , and PLv_GVC_F , which are weighted based on the domestic value-added directly absorbed by the importing country, indirectly absorbed by the source country, and indirectly absorbed by the third country, respectively. PL_GVC_R indicates that the domestic value-added only crosses the border once, representing the shallow participation in the GVC. PL_GVC_D and PLv_GVC_F indicate that domestic value-added crosses multiple borders, representing deep participation in the GVC. The results after decomposition are shown in Tables A1 and A2 in Appendix B. The changes in the three parts of each subdivision industry from 2000 to 2014 are shown in Figure 5.

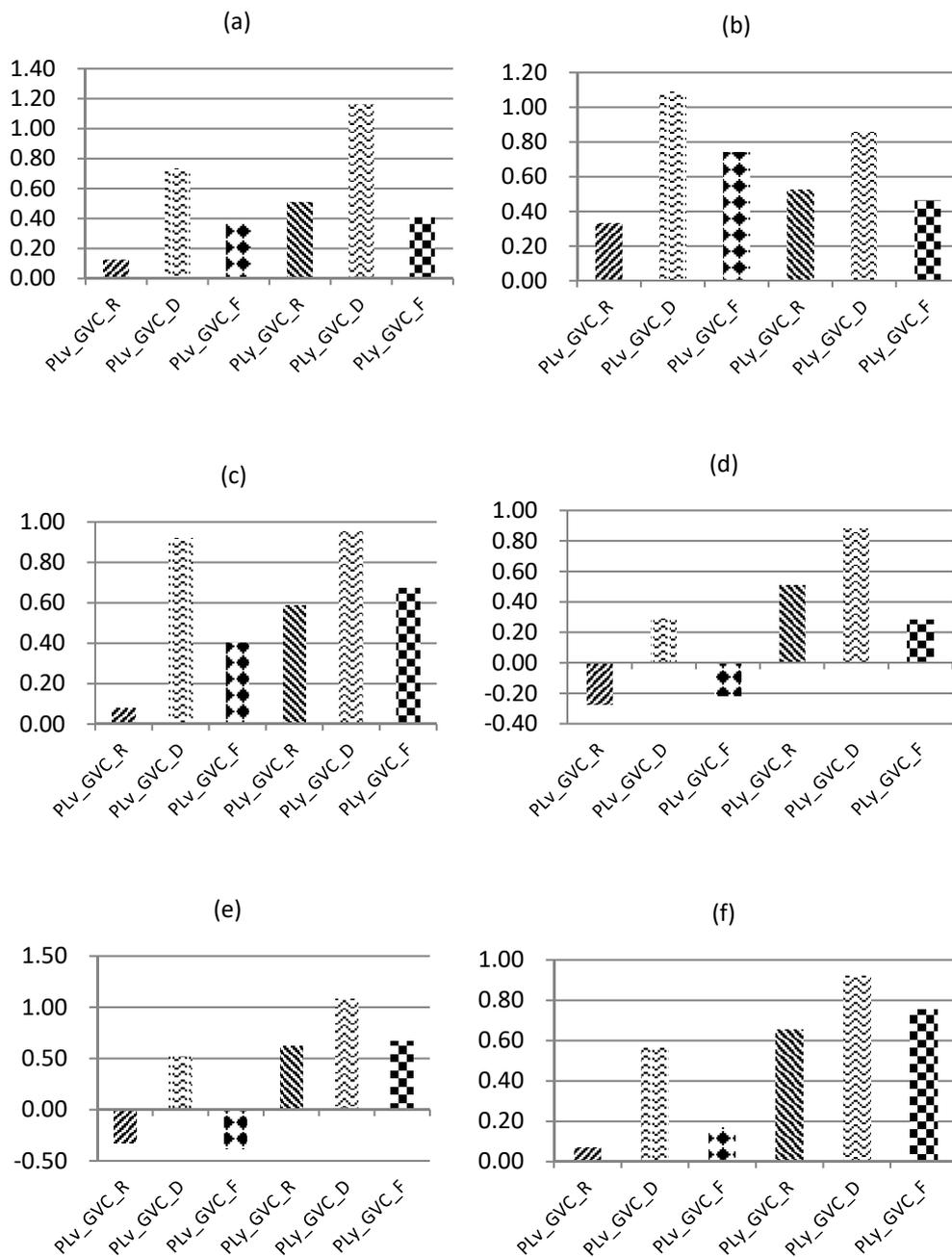


Figure 5. Changes in each part in the length of the GVC of China’s equipment manufacturing industry from 2000 to 2014. (a–f) represent manufacturing industries C25, C26, C27, C28, C29, C30. Data source: calculated and compiled according to WIOD and the Research Institute for GVC of the University of International Business and Economics.

As shown in Figure 5 and Tables A1 and A2, from 2000 to 2014, except for machinery and equipment manufacturing not elsewhere classified (C28) and the automobile, trailer, and semi-trailer manufacturing industry (C29), the lengths of all parts of the value chain of the remaining industries extended, which shows that the shortened forward lengths of the value chain of machinery and equipment manufacturing not elsewhere classified (C28) and automobile, trailer, and semi-trailer manufacturing industry (C29) are caused by the shortened parts, which are directly absorbed by the importing country and indirectly absorbed by other countries.

In addition, we found that the extension of complex cross-border production parts was significantly larger than that of simple cross-border production parts, no matter the forward or backward length of the GVC. This conclusion is consistent with Li's research on the length decomposition of GVCs in various sectors of Chinese manufacturing [43]. This indicated that the main driving force for the lengthening of the GVC of China's equipment manufacturing industry is complex cross-border production, that is, multiple border crossings before domestic value-added is converted into a final product. This also means that China's equipment manufacturing industry follows the general trend of the GVC division of labor, the degree of integration into the GVC has gradually deepened, and deep participation has increasingly become the main method of GVC embedding. Among them, the main factor driving the lengthening of complex cross-border production is the length of the indirect absorption by the source country, indicating that the domestic value-added implicit in the intermediate exports of China's equipment manufacturing industry did not ultimately achieve export profits.

4.1.3. Position of Chinese Equipment Manufacturing Industry in the GVC

The position index of China's equipment manufacturing industry in the GVC from 2000 to 2014 can be calculated according to Equation (16). On the whole, the GVC position index of the sub-sectors of China's equipment manufacturing industry was always less than 1, and it has always been downstream of the GVC. The GVC status of the equipment manufacturing industry is consistent with the research results reported by Wang [44]. It ranks lower among the 43 countries in the WIOD statistics and shows a downward trend as a whole because the forward length of the value chain is always shorter than the backward length and the gap is constantly widening.

Specific to the various sub-sectors, of the six industries, only the GVC position index of computer, electronics, and optical equipment manufacturing industry (C26) slightly increased and ranking improved, but it was still relatively low. The ranking of the machinery and equipment manufacturing industry not elsewhere classified (C28) fell the most severely, from 5th to 33rd, and fell faster after the 2008 economic crisis, and remained basically stable after 2011, which reflects that, in recent years, China's transfer of this industry has accelerated, some intermediate production links have been transferred to other countries, and China has imported from these countries to meet final demand. The GVC position index of the automobile, trailer, and semi-trailer manufacturing industry (C29) dropped significantly, with the ranking falling from 7th to 17th. The ranking of other transportation equipment manufacturing industry (C30) was unstable, but the overall trend was downward, mainly due to the frequent fluctuation of the forward length of its value chain. The rankings of metal products manufacturing (except mechanical equipment) (C25) and power equipment manufacturing (C27) were stable, fluctuating within the bottom 10. In particular, the manufacturing of metal products (except mechanical equipment) (C25) always ranked below 40. This can be explained by the following reasons: domestic raw materials cannot meet the needs of high-quality metal products, and some imported raw materials are required for production processing, and the technical level of China's metal product manufacturing enterprises is still relatively low, mainly for low-end products production, and some products cannot meet consumer demand and can only be obtained through imports.

According to the above analysis, although China's equipment manufacturing industry continues to participate in the GVC, low-end participation still dominates, which has led it to be in the downstream position in the GVC and face the low-end lock-in dilemma in the physical position. Changing China's image of "world factory" and "manufacturing power" appears to be problematic.

4.2. Economic Location

4.2.1. Overall Value-Added Export Rate of China's Equipment Manufacturing Industry

According to the definition of the total trade accounting framework, only the ratio of domestic value-added (DVA) absorbed by foreign countries to total exports can be used as a comprehensive statistical indicator to measure value-added exports. Therefore, we calculated the proportion of various

types of domestic and foreign value-added that ultimately participate in exports in total exports to measure the export capacity of value-added of Chinese equipment manufacturing in the GVC. For the export of an industry, the higher the domestic value-added export rate, the stronger the value-added export capacity of the industry. The lower the foreign value-added export rate, the weaker the value-added export capacity. Judging from the specific values, the domestic value-added export rate of China's equipment manufacturing exports was always much higher than the foreign value-added export rate, indicating that its value-added export capacity was still relatively strong. Among domestic value-added exports, direct value-added exports (DVA_FIN + DVA_INT) accounted for the highest proportion, indicating that China's equipment manufacturing industry was profitable in the GVC by directly exporting final products and exporting intermediate products for direct consumption by importing countries.

From the perspective of changes, in 2014, although the domestic value-added export rate of China's equipment manufacturing exports was basically the same as in 2000, we observed a slight decline. Its domestic value-added export rate experienced a slight increase in 2000–2001, a rapid decline in 2001–2004, a steady period in 2004–2007, a rapid recovery in the financial crisis period of 2007–2009, a small decline in 2009–2010, and a slow rise since 2010. The degree of decline was much higher than the increase. The changes and the range of change in foreign countries' value-added exports were exactly the opposite. This collectively showed that although China's entry into the WTO in 2001 accelerated the pace of China's equipment manufacturing industry's integration into the GVC, the benefits gained from participating in the international division of labor decreased. The financial crisis turned the situation around, but with the gradual recovery of other countries' economies, the pace of this change has slowed. The foreign value-added export rate decreased from 19.31% in 2000 to 16.81% in 2014, indicating that with the increase in the degree of participation in the international division of labor, China's equipment manufacturing industry has reduced its external dependence on upstream industries.

The above analysis showed that from 2000 to 2014, the proportion of export earnings obtained by China's equipment manufacturing industry in participating in GVCs declined slightly, and the export capacity of value-added increased slowly, which was strongly affected by the foreign economic environment.

4.2.2. China's Equipment Manufacturing Industry Segment Value-Added Export Rate

To study the changes in the value-added export capacity of China's equipment manufacturing sub-sectors in the GVC, we calculated and sorted the various value-added export rates in the exports of each sub-sector, as shown in Table 2.

First, from the perspective of domestic value-added exports, the domestic value-added rate of computer, electronics, and optical equipment manufacturing (C26) increased slightly. However, compared with the other sub-sectors, the industry's export capacity of value-added in participating in the GVCs was relatively poor. The domestic value-added export rate accounted for less than 70%. The domestic value-added rates of other sub-sectors reduced to varying degrees, the economic status of participating in the division of GVCs declined, and the profit situation deteriorated. Among them, the industry whose domestic value-added rate fell the fastest is the metal product manufacturing industry (except machinery and equipment) (C25), with a decline of 2.86%. This was followed by the machinery and equipment manufacturing industry not elsewhere classified (C28) in 2014, which decreased by 2.78% compared with 2000. The rise in the domestic value-added rate of the computer, electronics, and optical equipment manufacturing industry (C26) occurred due to the increase in the proportion of its direct domestic value-added exports. The metal product manufacturing industry (except machinery and equipment) (C25) declined the most in the domestic value-added export rate. This was due to the decline in the proportion of direct and indirect domestic value-added. The proportion of indirectly domestic value-added exports of power equipment manufacturing (C27), unclassified machinery, and equipment manufacturing (C28), and automobile, trailer, and semi-trailer manufacturing (C29)

increased slightly, but due to the large decline in the proportion of direct domestic value-added, the domestic value-added export rates of these three industries decreased. The small decline in the domestic value-added rate of other transportation equipment manufacturing (C30) was indirectly caused by the decline in the proportion of domestic value-added exports.

Secondly, from the perspective of foreign value-added exports, except for metal product manufacturing (except machinery and equipment) (C25) and unclassified machinery and equipment manufacturing industry (C28), the foreign value-added export rate increased by 0.3–0.4%. The rest of the sub-sectors declined, which led to a decline in the overall foreign value-added export rate of the equipment manufacturing industry.

The above analysis showed that although the sub-industries of China's equipment manufacturing industry increased their participation in the labor division of the GVCs, and most industries reduced their dependence on upstream industries, the proportion of the division of labor income they have obtained has declined, so the economic location of the GVC division of labor declined.

Table 2. The various value-added export rates of each sub-sectors of China's equipment manufacturing industry.

Industry	Total Export Billion US \$		Domestic Value-Added (DVA)(%)				Foreign Value-Added (FVA)(%)			
			DVA_FIN+ DVA_INT		DVA_INTrex		Export Implied Value-Added of Import Countries (MVA)		Export Implied Value-Added of Other Countries (OVA)	
			2000	2014	2000	2014	2000	2014	2000	2014
C25	7.214	84.998	6.837	6.677	1.502	1.377	0.176	0.259	1.074	1.027
C26	47.524	560.582	5.704	5.787	1.218	1.142	0.348	0.316	2.006	1.680
C27	17.851	221.114	7.096	6.784	1.031	1.107	0.227	0.286	1.305	1.217
C28	8.791	189.106	7.564	7.099	0.875	1.062	0.175	0.252	1.148	1.106
C29	1.698	60.889	7.120	6.798	1.407	1.565	0.180	0.193	1.007	0.937
C30	3.709	53.697	7.514	7.641	0.740	0.601	0.249	0.406	1.291	1.102

Data source: calculated and compiled according to WIOD and the Research Institute for GVC of the University of International Business and Economics.

5. Conclusions and Recommendations

In this study, we combined the length and location index of the GVC with the domestic value-added export rate, using the WIOD database to measure and analyze the physical and economic locations of the Chinese equipment manufacturing industry and its sub-sectors in the GVC. The conclusions are as follows:

(1) From a physical location perspective, China's equipment manufacturing industry is falling behind in terms of the GVC. The backward length of the value chain of each segmented industry is always longer than the forward length, and the gap between the two continues to widen. The situation at the downstream position of the GVC has intensified: complex cross-border production is the main driving force for the extension of the GVC of China's equipment manufacturing industry, and deep participation in the GVC has increasingly become the main method for China's equipment manufacturing industry to integrate into the GVC. The position index in the GVC of China's equipment manufacturing industry was always less than one, ranking behind in the WIOD statistics of 43 countries. China's equipment manufacturing industry is facing the low-end dilemma of physical location. The two industries with the deepest lock-in are metal products manufacturing (excluding machinery and equipment) (C25) and power equipment manufacturing (C27), the unclassified machinery and equipment manufacturing industry (C28), automobile, trailer, and semi-trailer manufacturing industry (C29), and other transportation equipment manufacturing (C30) have deepened their lock-up. Only the computer, electronics, and optical equipment manufacturing industry (C26) weakened its lock-up, but the low-end lock-in dilemma has not been overcome.

(2) From the perspective of economic location, since China's entry into the WTO in 2001, the export capacity of value-added of China's equipment manufacturing industry in the GVCs has weakened, but it gradually increased after the economic crisis in 2008 and was strongly affected by

the foreign economic environment. For the entire equipment manufacturing industry, the proportion of gains in the division of labor in the GVC declined, and the degree of low-end lock-in in the economic location deepened. From the perspective of various sub-sectors, the automobile, trailer, and semi-trailer manufacturing industry (C29) had the weakest lock-up. The computer, electronics, and optical equipment manufacturing industry (C26) had the deepest lock-up, which slightly weakened. The degrees of lockups in other segments have deepened.

Based on the above conclusions, to accelerate breakthroughs in the low-end lock-in status of China's equipment manufacturing industry in the GVC, we propose the following suggestions:

(1) In response to the "intelligent manufacturing" strategy, the development of enterprises' intelligent manufacturing and the support of government funds and policies should be strengthened. Enterprises should follow the intelligent manufacturing development trend and transform into intelligent and information-based production [45]. From large-scale manufacturing to intensive manufacturing transformation, the construction of intelligent factories, the introduction of intelligent equipment, process upgrading, and technological progress improve product quality and technology content, reduce production costs, improve efficiency, and then improve product quality added value. The government should strengthen policy support, fully use the existing fund channels such as the special construction fund, and give preferential treatment and support to the intelligent transformation of equipment manufacturing enterprises. Simultaneously, financing channels should be strengthened. The innovation activities of Chinese enterprises are mainly restricted by internal financing [46]. Therefore, the government should encourage the development of private financial institutions, introduce foreign financial institutions, ease the financing constraints of enterprises, accelerate the intelligent manufacturing upgrading of small- and medium-size enterprises, and provide financial support for Chinese enterprises to move up the GVC [11].

(2) With the help of "Internet +", the service-oriented development of China's equipment manufacturing industry should be accelerated. In the value chain, "Internet +" can promote manufacturing enterprises and suppliers to realize network collaboration in the production and sales links, which would reduce intermediate costs, improve efficiency, and develop toward the direction of "manufacturing + service" for China. Therefore, investment should be increased in national service elements and, in R&D design, after-sales service, and other aspects, the overall level of equipment products should be improved. The development of new generation technology should be accelerated, the collaborative development of manufacturing and service should be promoted with digitization and networking to expand and extend the value chain [47].

(3) The home market should be cultivated, the domestic market demand should be expanded, and the market space for China's equipment manufacturing industry should be broadened to break overcome the low-end locking dilemma. China's equipment manufacturing industry is strongly affected by the foreign economic environment and has a strong dependence on external markets. This will inevitably cause Chinese equipment manufacturing enterprises to be constrained by foreign leading enterprises, making it difficult to break through the low-end lock-in situation. Therefore, China needs to work hard to cultivate the home market, promote the rationalization of the domestic demand structure, and rely on the "mother market effect" of domestic demand and the internal mechanism for promoting innovation in domestic demand to gradually eliminate the development dilemma of "two ends outside". Simultaneously, companies must adopt information technologies such as the Internet, big data, and e-commerce to fully tap potential consumer demand, improve product quality and grade, and achieve higher levels of supply and demand matching, thereby enhancing the company's international competitiveness and climbing to higher added value links in the GVC.

(4) The ability of enterprises to innovate independently should be improved, the dependence of technology on foreign countries should be reduced, and the technological blockade in developed countries needs to be broken. Technology is the primary productive force. The level of an enterprise's technological innovation ability determines whether an enterprise can survive the fierce competition in the market. Therefore, Chinese enterprises must change their development thinking, start from

learning and drawing on advanced foreign technologies, gradually transform to independent research and development, create key core technologies belonging to the enterprise, fundamentally improve the technological innovation capabilities of China's equipment manufacturing industry, and strengthen the industry competitiveness. The government should also provide adequate support for technological innovation, use tax means to promote the export of enterprises and encourage enterprise innovation. The adjustment of China's export tax rebate policy to promote the extension of enterprises' export period also contributes to their export stability [48]. Therefore, tax incentives should be provided to independent research and development enterprises, and export tax rebates should be strengthened to encourage enterprises to increase exports and promote the sustainable development of the equipment manufacturing industry.

(5) China's equipment manufacturing industry should be achieved with the transformation to low carbon. As early as 2012, China placed sustainability and low-carbon economic strategy at its core. Sustainable development and innovation strategy can provide value for enterprises and society and enhance the competitiveness of countries [49]. To hasten China's low carbon economic transformation, promoting sustainable economic development is essential. The equipment manufacturing industry, as an important part of the country's industrial economy, must take the lead in the transition to a low-carbon economy to realize the traditional industry upgrade. Therefore, to use existing low carbon lock-in technology to break through traditional manufacturing technology, the high pollution, and high emissions industry must transition into low pollution and low emission industry, supporting the ecotype, developing the energy-saving equipment manufacturing sector, increasing energy-saving technology research and development, encouraging enterprises through technical innovation, building internationally renowned low-carbon brands, relying on the brand value, enhancing the international competitiveness, and achieving further low-end locking breakthroughs in the equipment manufacturing industry in the GVCs.

The focus of this study was to examine the physical and economic location of China's equipment manufacturing industry in the GVC. However, since the latest data on the official WIOD database website is only in 2014, we were unable to capture the trend of change in the past four years. Research is lacking on the formation path and external factors of low-end lock-ins, such as trade policy and international environment. Future research should focus on the impact of trade policies and the international environment on the low-end lock-in of the equipment manufacturing industry, and analyze the potential of overcoming low-end lock-ins.

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Appendix A

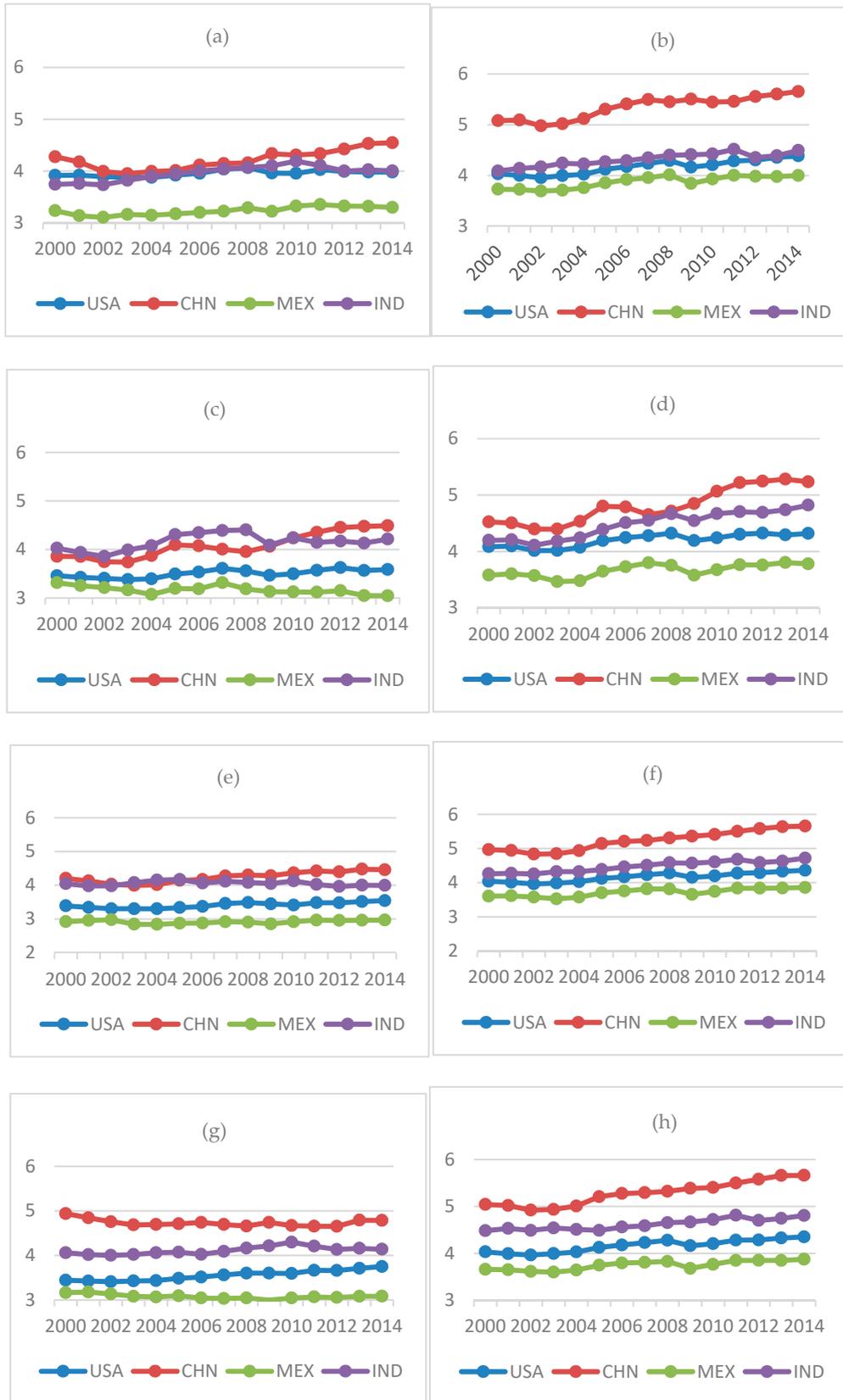


Figure A1. Cont.

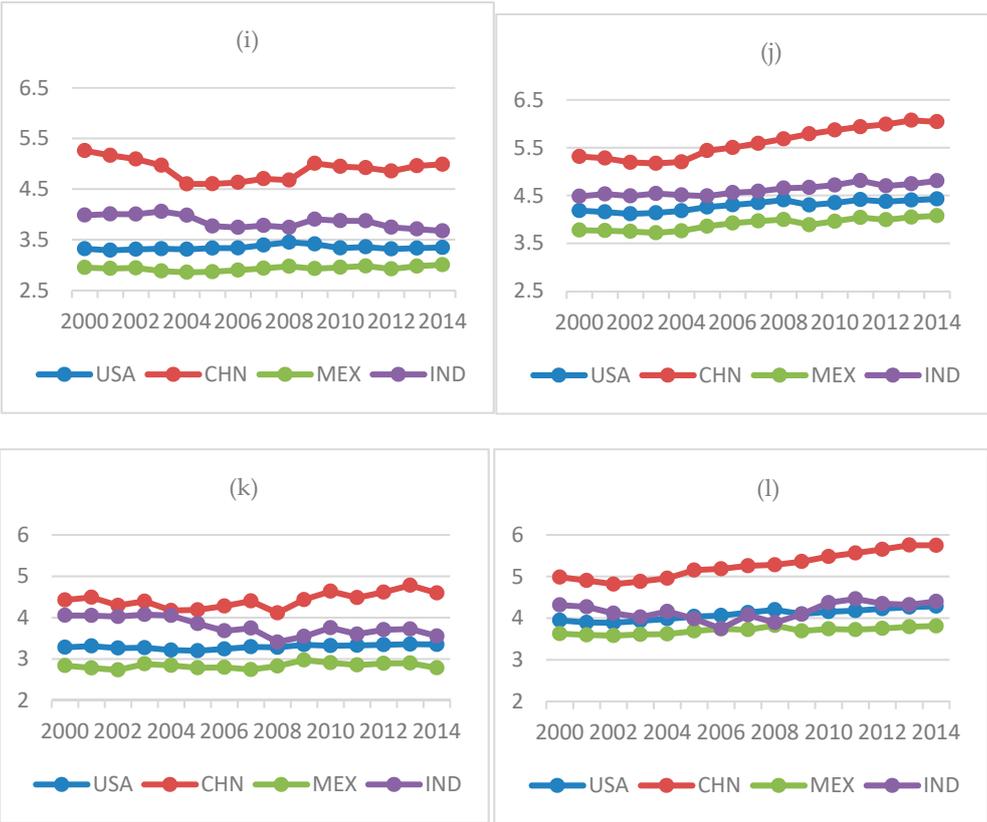


Figure A1. The length of the GVC of each subdivision industry in the United States, Mexico, India, and China’s equipment manufacturing industries. (a), (c), (e), (g), (i), (k) represent the forward length of the GVC of manufacturing industries C25, C26, C27, C28, C29, C30 respectively. (b), (d), (f), (h), (j), (l) represent the backward length of the GVC of manufacturing industries C25, C26, C27, C28, C29, C30 respectively. Data source: calculated and compiled according to WIOD and the Research Institute for GVC of the University of International Business and Economics.

Appendix B

Table A1. Decomposition of the forward length of the GVC of China's equipment manufacturing industry.

Industry	Part	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
C25	PLv_GVC_R	3.83	3.74	3.56	3.51	3.51	3.50	3.57	3.61	3.61	3.82	3.76	3.75	3.84	3.92	3.95
	PLv_GVC_D	6.86	6.75	6.47	6.44	6.52	6.72	6.70	6.74	6.82	7.15	7.17	7.24	7.39	7.53	7.59
	PLv_GVC_F	5.11	4.99	4.82	4.77	4.83	4.89	4.97	5.02	5.04	5.21	5.17	5.19	5.30	5.44	5.48
C26	PLv_GVC_R	3.64	3.66	3.53	3.48	3.58	3.77	3.73	3.61	3.55	3.72	3.83	3.93	4.02	3.96	3.97
	PLv_GVC_D	5.25	5.25	5.04	5.02	5.16	5.45	5.40	5.23	5.26	5.66	5.91	6.08	6.13	6.28	6.34
	PLv_GVC_F	3.94	3.90	3.79	3.79	3.92	4.15	4.12	4.09	4.06	4.12	4.30	4.41	4.50	4.63	4.68
C27	PLv_GVC_R	3.82	3.75	3.65	3.59	3.58	3.66	3.66	3.77	3.79	3.81	3.85	3.87	3.84	3.90	3.90
	PLv_GVC_D	6.28	6.22	5.99	6.01	6.14	6.43	6.46	6.54	6.57	6.77	6.83	6.96	6.98	7.14	7.19
	PLv_GVC_F	4.71	4.64	4.51	4.52	4.57	4.77	4.80	4.91	4.95	4.89	4.95	5.01	4.99	5.10	5.11
C28	PLv_GVC_R	4.54	4.46	4.37	4.28	4.26	4.25	4.26	4.23	4.18	4.30	4.20	4.16	4.15	4.27	4.27
	PLv_GVC_D	7.40	7.29	7.09	7.08	7.16	7.38	7.39	7.29	7.25	7.43	7.34	7.39	7.46	7.66	7.69
	PLv_GVC_F	5.55	5.42	5.33	5.26	5.28	5.31	5.33	5.24	5.19	5.26	5.16	5.12	5.14	5.31	5.33
C29	PLv_GVC_R	4.85	4.76	4.70	4.56	4.22	4.21	4.22	4.28	4.24	4.60	4.51	4.45	4.40	4.49	4.53
	PLv_GVC_D	8.09	8.03	7.85	7.83	7.69	7.95	7.97	8.05	7.97	8.30	8.32	8.35	8.41	8.59	8.61
	PLv_GVC_F	5.92	5.85	5.74	5.60	5.12	5.12	5.15	5.24	5.23	5.57	5.50	5.50	5.41	5.50	5.54
C30	PLv_GVC_R	4.05	4.10	3.90	3.98	3.75	3.74	3.81	3.94	3.67	4.03	4.17	3.99	4.09	4.26	4.12
	PLv_GVC_D	7.07	7.20	6.87	6.97	7.08	7.32	7.35	7.29	7.12	7.42	7.54	7.36	7.45	7.75	7.64
	PLv_GVC_F	4.99	5.12	4.92	5.03	4.78	4.85	4.91	5.00	4.67	4.96	5.23	5.05	5.32	5.42	5.16

Data source: calculated and compiled according to WIOD and the Research Institute for GVC of the University of International Business and Economics.

Table A2. Backward length decomposition of the GVC of China's equipment manufacturing industry.

Industry	Part	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
C25	PLy_GVC_R	4.55	4.58	4.46	4.49	4.57	4.74	4.81	4.88	4.85	4.96	4.89	4.90	4.99	5.02	5.06
	PLy_GVC_D	7.09	7.11	6.91	6.98	7.09	7.55	7.70	7.84	7.80	8.00	7.89	7.86	7.99	8.14	8.25
	PLy_GVC_F	5.67	5.61	5.40	5.41	5.48	5.63	5.71	5.83	5.83	6.01	5.85	5.87	5.99	6.04	6.08
C26	PLy_GVC_R	3.92	3.91	3.77	3.75	3.86	4.10	4.05	3.87	3.93	4.15	4.33	4.46	4.49	4.50	4.44
	PLy_GVC_D	6.08	6.00	5.76	5.76	5.95	6.29	6.25	6.16	6.24	6.44	6.53	6.66	6.70	6.84	6.94
	PLy_GVC_F	4.72	4.70	4.53	4.44	4.54	4.78	4.73	4.65	4.72	4.79	5.01	5.18	5.19	5.24	5.19
C27	PLy_GVC_R	4.43	4.42	4.30	4.30	4.37	4.56	4.59	4.60	4.67	4.79	4.81	4.90	4.98	5.01	5.02
	PLy_GVC_D	6.85	6.79	6.57	6.55	6.67	7.04	7.06	7.10	7.19	7.37	7.34	7.43	7.51	7.68	7.80
	PLy_GVC_F	5.29	5.24	5.05	5.09	5.19	5.40	5.44	5.48	5.63	5.71	5.73	5.84	5.93	5.97	5.96
C28	PLy_GVC_R	4.51	4.50	4.39	4.39	4.44	4.62	4.66	4.66	4.68	4.81	4.80	4.88	4.97	5.03	5.02
	PLy_GVC_D	6.96	6.92	6.71	6.71	6.83	7.17	7.22	7.26	7.28	7.46	7.40	7.47	7.54	7.73	7.84
	PLy_GVC_F	5.96	5.90	5.71	5.66	5.65	5.84	5.84	5.70	5.78	6.01	5.91	6.01	6.16	6.23	6.24
C29	PLy_GVC_R	4.78	4.77	4.67	4.63	4.64	4.85	4.89	4.95	5.05	5.22	5.28	5.33	5.39	5.45	5.40
	PLy_GVC_D	7.36	7.33	7.17	7.15	7.16	7.52	7.61	7.74	7.78	8.05	8.06	8.10	8.19	8.37	8.44
	PLy_GVC_F	6.54	6.56	6.44	6.41	6.40	6.62	6.62	6.66	6.80	7.07	7.08	7.09	7.13	7.23	7.21
C30	PLy_GVC_R	4.45	4.39	4.28	4.34	4.39	4.56	4.56	4.62	4.64	4.78	4.87	4.94	5.03	5.11	5.10
	PLy_GVC_D	7.02	6.99	6.77	6.73	6.84	7.17	7.19	7.24	7.28	7.49	7.47	7.57	7.61	7.84	7.94
	PLy_GVC_F	5.67	5.59	5.54	5.45	5.52	5.70	5.62	5.70	5.74	5.85	5.92	6.06	6.17	6.37	6.42

Data source: calculated and compiled according to WIOD and the Research Institute for GVC of the University of International Business and Economics

Table A3. The expressions of the definition of abbreviations in the paper.

Abbreviation	Definition
GVC	Global value chain
WIOD	World input–output database
VS	Vertical specialization
VAX	Value-added export
V_GVC_R	Domestic value-added of source countries directly absorbed by importing countries in bilateral intermediate exports
V_GVC_F	Domestic value-added in bilateral intermediate exports that are indirectly absorbed by the direct importing country or re-exported to a third country
V_GVC_D	Domestic value-added returned from bilateral intermediate exports and absorbed by the source country
PL_GVC	GVC production length
PLv_D	Pure domestic production length
PLv_RT	Traditional trade production length
PLv_GVC_R	Domestic value-added only crosses the border once
PLv_GVC_D	GVC production length absorbed by source country
PLv_GVC_F	GVC production length absorbed by other countries
DVA	Domestic value-added absorbed abroad
RDV	Domestic value-added returned and absorbed by the country
FVA	Value-added abroad
DVA_FIN	Domestic value-added of final exports
DVA_INT	Intermediate exports absorbed by direct importing countries
DVA_INTrex	Absorbed by direct import production and export to third countries
DDC	Pure double counting part from domestic accounts
MVA	Export implied value-added of import countries
OVA	Export implied value-added of other countries
FDC	Pure double counting from a foreign account

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